TELESCOPE MAKING 33

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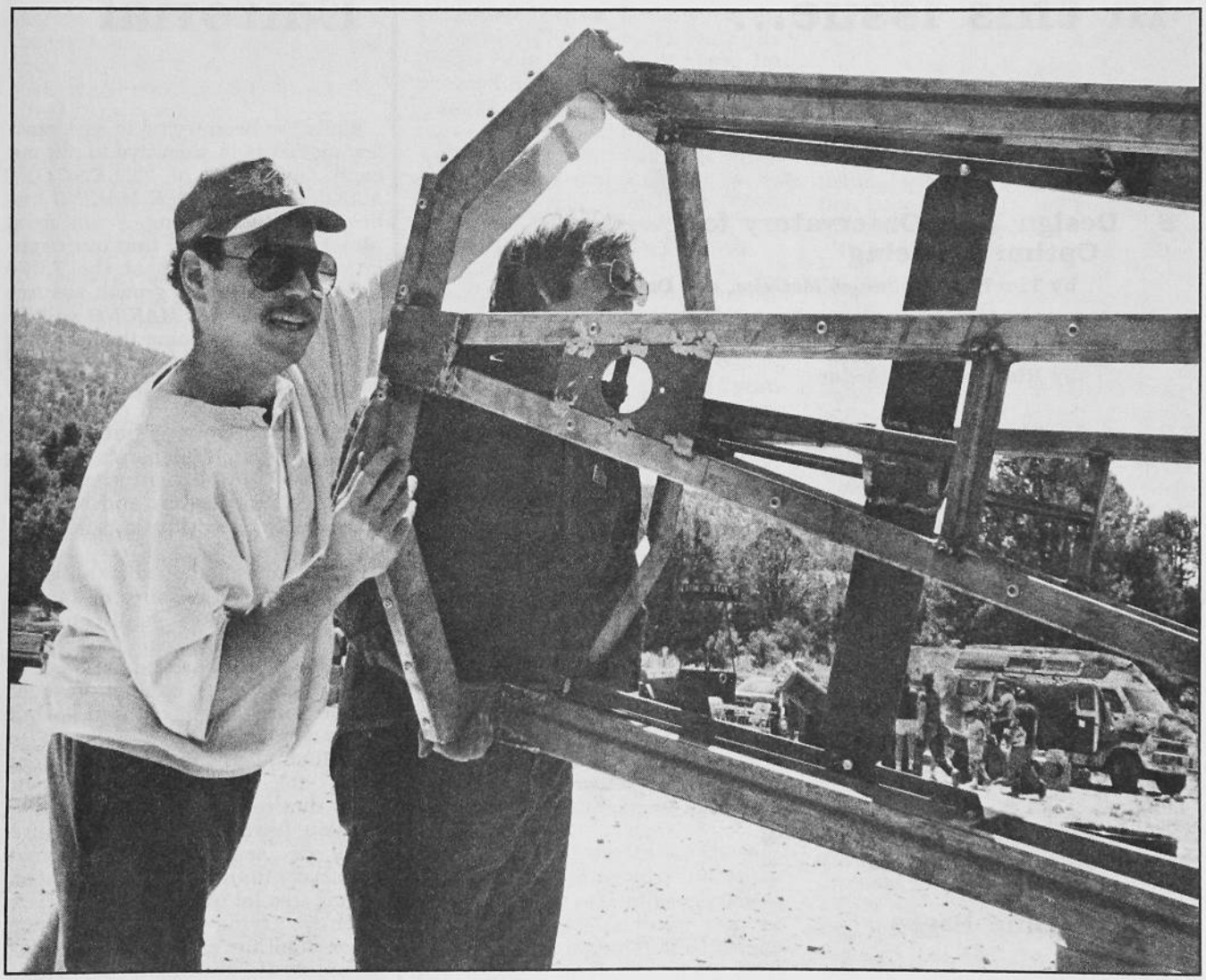
The magazine *for*, *by*, and *about* telescope makers! **Summer 1988**



RIVERSIDE 1988

Telescope Making #33

The magazine *for, by,* and *about* telescope makers!

Editor: Richard Berry
Associate Editor: Robert E. Cox
Managing Editor: Stephen Cole

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In this issue...

2 Editorial
3 Letters

8 Design Your Observatory for Optimum Seeing
by Tim Hunter, James McGaha, and David Crawford

14 In Search of the Perfect Eyepiece
by Richard Buchroeder

18 A Method of Making Precision Worm Gears
by John Wright

20 Remote Control Collimation
by Jack Lowenstein

22 Building a Precise Shutter
by Jeff Beish and Donald Parker

24 The 1988 Riverside Telescope Makers Conference
by Richard Berry

38 Efficient Mirror Testing
by Robert C. Follett

46 The Blue Pages

Cover: The LAAS 31-inch Newtonian/Cassegrain at Riverside.

Editorial

While I've been trying to squeeze a few moments in sideways to put out each new issue of *TELESCOPE MAKING*, *TELESCOPE MAKING* has been quietly growing. I am most pleased to announce that our circulation has pushed past the 7,000 mark, and that this growth assures that *TELESCOPE MAKING* will be around for quite some time. I'd like to take this opportunity to thank each and every subscriber for your loyalty and support.

Please remember that a little magazine like *TM* depends entirely on its readership for survivial. Without your readership, and without your article contributions, there's no magazine at all.

I'd like to remind our new subscribers that all back issues of *TM* are in print, so you can still complete your collection. I can't guarantee that this will always be the case — it's expensive to go back to press for a short run of a sold-out issue — but that's what we've been doing up 'til now. If you want to play safe, order your back issues now while you know they're still available.

If you haven't already, I'm sure you'll soon see that the apochromat debate continues to heat up. I been talking to a lot of people about apos recently, trying to psych out the cause of all the rancor. (As one correspondent commented, "Apos seem to be more attractive to opticists than beautiful members of the

opposite sex.") Well, maybe that's true, but the main attraction, I think, is the challenge lenses offer.

Apochromats and superachromats offer limitless opportunity for technically "sweet" solutions. Over a vast array of glasses and over countless combinations of curves, the lens designer holds dominion. Rising from the mass of mediocre lenses are pinnacles of perfection -- and these pinnacles are the holy grails of the lensmaker's quest.

The disagreements arise not from optics, but rather from the definition of what constitutes a *desirable* lens. Even as one opticist seeks an ultimate optic with no discernible color and another looks for high-quality low-cost designs, a third wants to make the most compact possible telescope and is willing to accept a fair amount of color, while a fourth wants to hack around pushing glass. As I see it, the crux of the problem is that each opticist finds it difficult to accept the design goals and boundary conditions that others have assumed.

This can't continue. We face more than enough problems in designing apochromats and superachromats that we don't need to waste energy disagreing about design goals.

We've got to define what counts. The number of axis crossings (usually two for an achromat, three for an apochromat, and four for a superachromat) is a figure sometimes waved like a red flag in the face of other opticists, but it isn't all that meaningful. "The paraxial design may have all these crossings," says John Gregory, "but when those rays get off axis other things start to happen." That's when spherochromatism and other ugly optical monsters rear their heads, and ordinary telescope makers retreat.

So I'm looking for one or more opticists to write an article for *TM* showing how apos and superachros work, how they're designed, and how the designer finds a design with acceptable design tradeoffs. I'd like to publish that article in *TM* so that as more and more powerful raytrace software becomes available, we can all participate in the quest for a desirable lens, however we define it.

I'd like to see more TMs try these lenses. For those who do, I'll be glad to make space in *TM* for your articles when they're ready. Anyone who brings together skills in fine glassworking, machining, and lens design deserves the space to tell his (or her) story.

— Richard Berry

Letters

Apo Club Progress

Dear Richard/ With all the interest in building apochromats expressed in *TM#31* and *TM#32* articles and letters, I thought you might like a progress report on our 8-inch Apo Club.

Members are from California to Massachusetts, Wisconsin to Texas, and one in England (Allan Mackintosh of Maksutov fame). Based on the design disclosed in the June 1987 *Sky & Tel*, notes in *TM#30*, and the September *S&T*, page 317, we made a group buy of eight sets of FKO1 and SK16. The glass was delivered around the first of this year.

All except one set were edged and generated here at Gregory Optics. We offered 10-inch Pyrex tools generated both sides for R1 and R4. During all this work (forty-two generations and fourteen edgings) not one blank was chipped or cracked — so we beat the odds once again, especially on the high expansion FK01. By press time, all lenses should be well into polishing, hoping to meet the Martian deadline.

A quick comment on the 8-inch prototype that I first mounted and used a week before the 1987 Texas Star Party. It was made from Schott FK52, ordered to grade-B specs (!), and showed a smooth cutoff by autocollimation in the shop. Yet when I set it up at the TSP 87, much to my surprise and consternation, it showed undercorrected spherical. What I didn't fully appreciate at the time were the thermal gradients still present from a sunny day spent soaking the scope in a closed Honda.

Many further observations made this year have confirmed the fine figure of this lens, as shown by identical star disks inside and outside focus and the associated rings. Two hours are more than enough cooling time here in Texas, when going from storage in an unheated garage. Surely the time is nonlinear with aperture.

The final melt design for the Apo Club has no coma and no spherochromatism, so, unlike cemented lenses, the residual color may be shown by a true graph of color *versus* change in focal legnth. The graph is a scaled plot of focal shift in percentage of focal against wavelength. The graph can be compared with true scale plots for any other lens corrected for spherochromation, no matter whether they use fluorcrown glass, calcium fluorite crystal, or whatever.

The plot of height in the focal plane versus entering height -- essentially an H *versus* tan U' plot as described in TM#21 -- is included for comparison with the curves shown in the June *S&T* article, page 663.

As that article's title implies, this is a *quest* not a *contest*. I feel the 8-inch f/15 is at the end of one trail. I'm hopeful another trail would end with an f/8 spherical solution of equally good color correction, zero lateral color and coma, using inexpensive glass.

Perhaps two other trails have already ended, giving Buchroeder's Tri-Schiefspiegler and Jim Daley's Schupmann rejuvenation.

John Gregory
Star Route A
Dripping Springs, TX 78620

Schalck-Newtonian Update

Dear Richard/ Thank you for publishing my design in *TM#31*. I notice, now, that there are a few items that need to be updated.

There is a hard aperture stop 290mm diameter in front of the tube; it helps in some of the correction. It's marked as surface #1 on the optical specifications.

The little "a" on the radius axis in figure 3.2 marks the Airy disc requirement. Please note that figures 4.0, 4.1, 4.2, and 4.3 are plotted in three colors: yellow, blue and red.

Finally, in the second to last paragraph, the reference to radii 3 and 5 should have read 3 and 6. My mistake!!

Thanks again, see you at Riverside!!

Robert Schalck
Allergan Humphrey
3081 Teagarden Street
San Leandro, CA 94577

Are We *Makers* or *Buyers*?

Dear Telescope Making/ I have enjoyed the hobby of telescope making for years. I take vigorous exception to some viewpoints offered in the letters from Mr. Back and Mr. Christen in TM#32.

First Mr. Back's letter: Just how long does Mr. Back believe John Gregory has had the 8-inch lens? John had only recently finished the lens before TSP.

Let's see your FK01/ZK9 doublet design, Mr. Back, and let's all line up

Letters

and view through this doublet. Let's compare yours against John's.

Why does the Gregory lens have to be *sold* to amateurs? A lot of us enjoy *making* optical components. Since when is the ability to *sell* a lens a criterion for its merit?

Although Mr. Back says FK01/ZK9 was the "perfect" combination, he complains about thermal effects of the FK glass and cool-down time. I'd like him to make up his mind.

Now for Mr. Christen's letter.

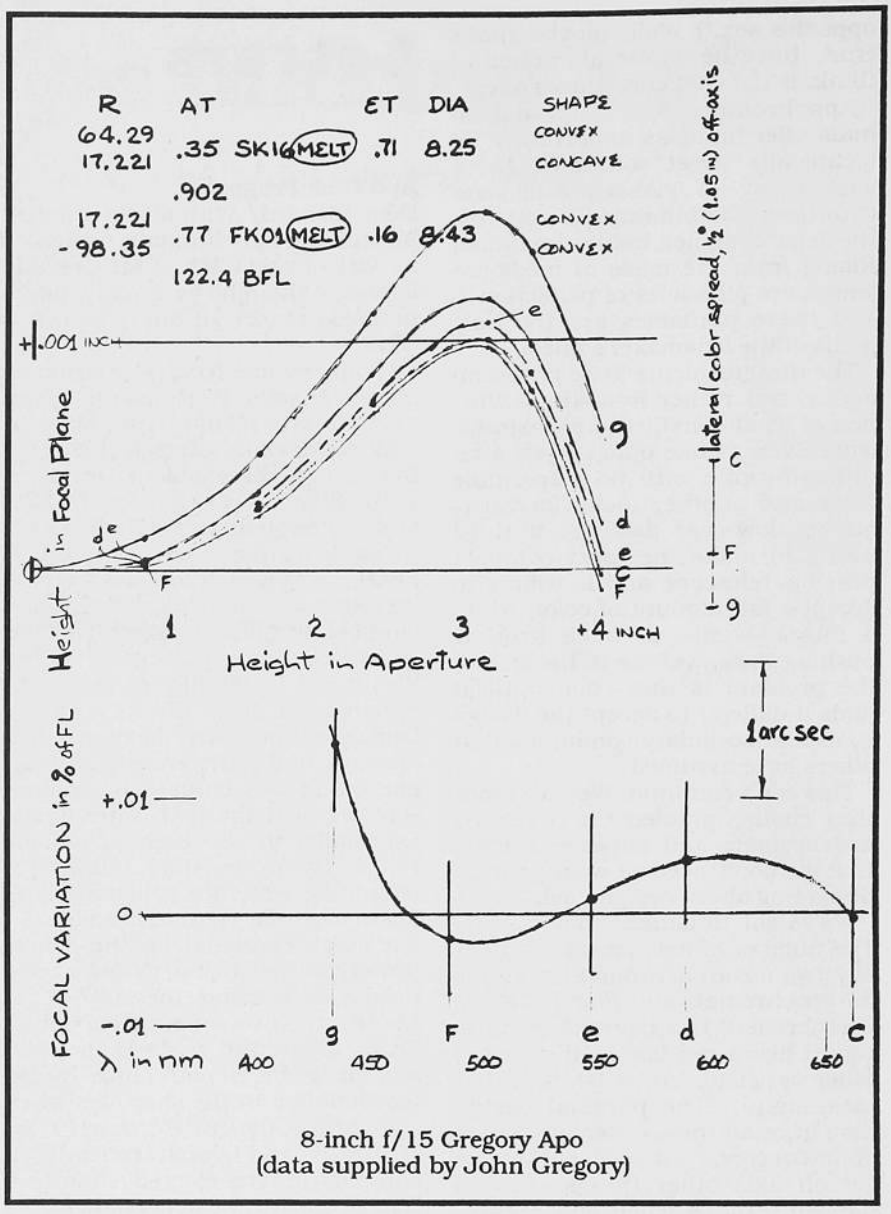
In paragraph four, where are the reports in *TM* and *S&T* from these "number" of owners of "small Japanese fluoride refractors" whose objectives "met their doom?" I call on Mr. Christen to substantiate these claims publicly in detail or retract this statement.

In paragraph five, Mr. Christen writes: "This design fits the bill for an amateur who has lots of time to figure and aspherize...." GREAT! What's wrong with that? We amateurs are not obligated to produce designs that some commercial outfit can turn a quick buck on. The fun of being an amateur is trying out new designs and either enjoying our successful products or learning from our mistakes.

From paragraph six, would Mr. Christen please explain to us "little guys" what "extreme" internal curvatures have to do with thermal equalization? Radii of 17 inches are not unreasonably steep, and their connection with thermal gradients and imagery is not at all clear. I was also not aware of Gregory's doublet having "perfect" color correction. Just excellent.

I would like to read Bob Chamberlin's response to Christen's appraisal of Schott's glass being 30 percent unusable (paragraph seven). Bob is the West Coast rep for Schott, and I am mailing him a copy of TM#32 for review.

Paragraph nine. This one hurts me the most, especially because the basic and most special, important purpose of this magazine is telescope *making*. Mr. Christen specifically states "an optical system is really worthwhile only if it can be purchased by the average amateur and remain a lasting value." Does Mr. Christen resent us "little guys," who enjoy designing and fabricating our own telescope optics to the highest accuracy achievable, instead of buying his objectives?



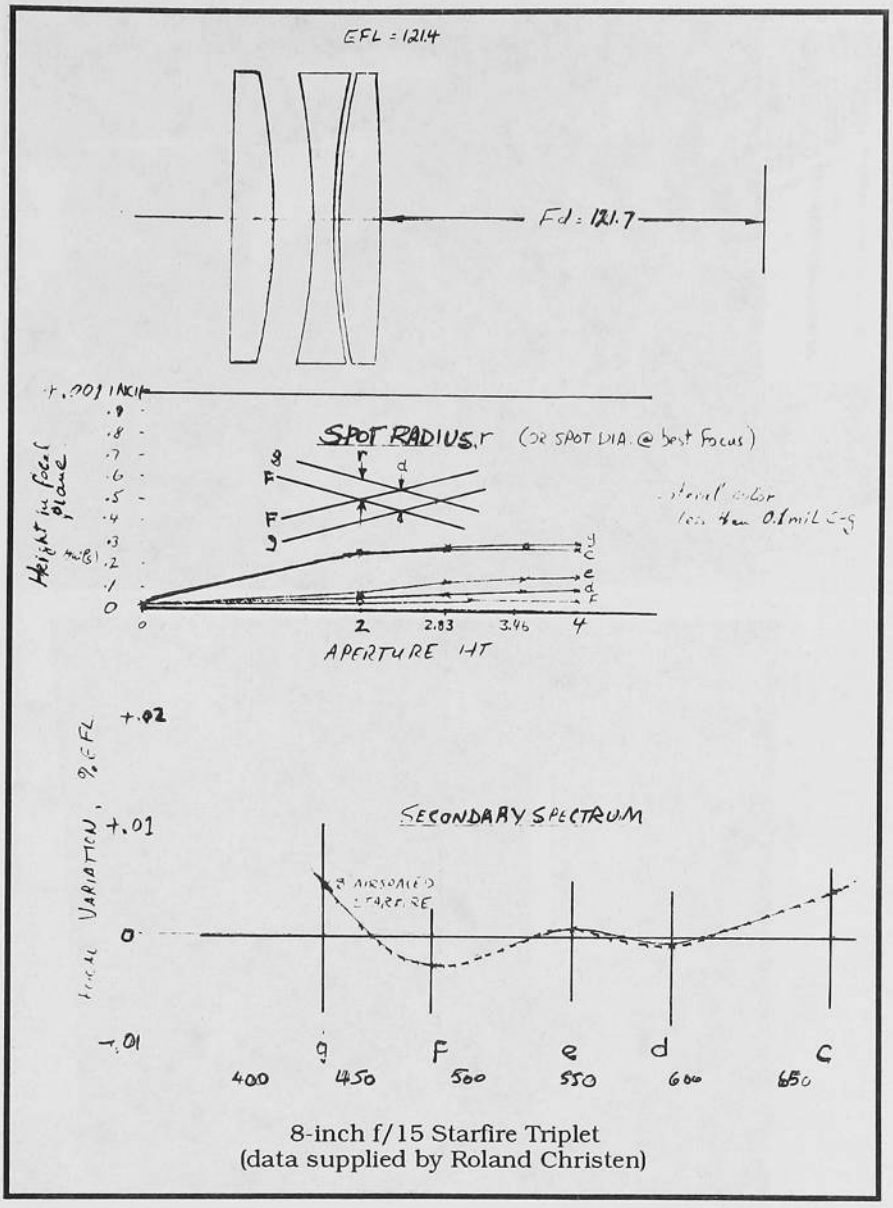
8-inch f/15 Gregory Apo
(data supplied by John Gregory)

Presumably our hobby cuts into his ability to "put food on the table and pay the bills." I have never even heard of such reaction to amateur telescope making before, and I for one do not feel the least bit guilty.

Last, Mr. Christen boldly states that he has "triplet designs that have color correction equal to or better than the Gregory doublet." Recall his description in the second paragraph, that John's doublet is "perfect." Seems contradictory. Why doesn't he publish the best of these designs for all to see, analyze, and confirm? John was kind enough to share his publicly. And his design checks out, both on paper and in the field.

I have observed over the years that Mr. Christen is a capable optical designer and fabricator. However, I feel I must remind him that there is plenty of room on this planet for other apo designers and lens grinders. I know John Gregory well enough to know he did not design and build his lens to compete against Astro-Physics. He did it for the same reason that most of us amateur opticians understand -- the sheer indescribable enjoyment and satisfaction of having designed and crafted optical systems by our own minds and hands, sometimes using optical design software of our own writing, and the thrill of viewing perfect diffraction patterns and sharp, crisp lunar and planetary images when the winds aloft allow.

I personally refuse to accept the implication that the telescopes I



8-inch f/15 Starfire Triplet
(data supplied by Roland Christen)

have designed and built are not worthwhile. I've enjoyed each thoroughly and fully intend to continue improving my design and fabrication skills through the coming years.

Mike Jones
416 Larchmont Way
Azle, TX 76020

Break Down for Portability

Dear Mr. Berry/ I would like to comment on Mr. Bob Cox's remark in *Telescope Making #31* Editorial. He made the comment: "But portability forces makers into compromises, and often those compromises result in lower optical quality. Sad to say, the average 12-inch f/8 reflector of twenty years ago was a far better all-around telescope than the f/4 to f/5 telescope we see today -- but it was a real beast, too big for portability."

This is not exactly true. In 1972 I purchased a set of mirrors from Coulter Optical Co. The primary mirror is an f/8 12.5-inch mirror. I agree with Mr. Cox that my optics are second to none for the size. But I love my scope, and I have also taken steps to make it portable. Although it requires two people to set up, I feel my scope is easily transported to darker skies.

One thing I have done to increase the portability was to cut the tube into three sections that can be bolted together. I got this idea from the article of the 20-inch telescope in *Telescope Making #7*. I'm amazed that the scope needs very little collimation after each assembly.

I also bought a trailer to haul my 300-pound pipe fork mount out of town. My dad works for a utility company in Iowa City, Iowa. We welded together a pipe fork mount, with used 2-inch and 4-inch gas main pipe -- I received a 4-inch tee for Christmas in 1974. This was the only purchased pipe in the mount.

I am currently using a Dobsonian type mount while I recondition the equatorial fork. I plan to take it to west Texas this spring for the Texas Star Party. I hope to have the equatorial mount finished, but if not I'll take the Dobsonian type mount. It's a hard telescope to miss -- the only 12.5-inch f/8 scope I know with a hexagonal plywood tube.

Mike Hotka
2410 Richland
Garland, TX 75042

Draper Machine Available

Dear *Telescope Making*/ I have a very unique professional power tool known as a Draper Machine primarily for lens and mirror grinding. I obtained it from Federal Surplus. It is complete and in working order with four-speed pulleys, a 1/2-horse 120-volt single-phase motor, and four turntables that fit on a Morse taper spindle. There is an optional reciprocating arm that carries the work across the faces of the rotating turntables, which can be impregnated with various grinding or polishing abrasives.

I have no idea what the going price for such a critter would be. I have resisted the urge to cannibalize the unit for its very unique mechanisms because I've sensed its inherent value to someone involved in lens making. It is a heavy beast, possibly 300 to 500 pounds, on dolly wheels with a heavy cast frame.

Please advise.

Paul A. Shealer
Evergreen Acres
R.D. #2, Box 14
Auburn, PA 17922

-- Take the best offer you get.

Trailer Testimonial

Dear Sirs/ I read with interest the article on trailering scopes in *TM#31*. Eugene Astronomical members have had some eight years experience with trailered telescopes. A trailered scope sidesteps the drawbacks of a permanently sited observatory: cost, security, and the chance that lights will overrun the site in the future.

For the person living in town, a trailered scope means the chance to conveniently get to dark skies

Letters

with a large scope -- dark skies being particularly needed for big apertures. Our club is also very interested in bringing astronomy to the public. Instead of asking the public to drive to remote observatories -- which many people will not do -- the trailered scopes are used to bring astronomy to them at the local science center, at parks, and at schools.

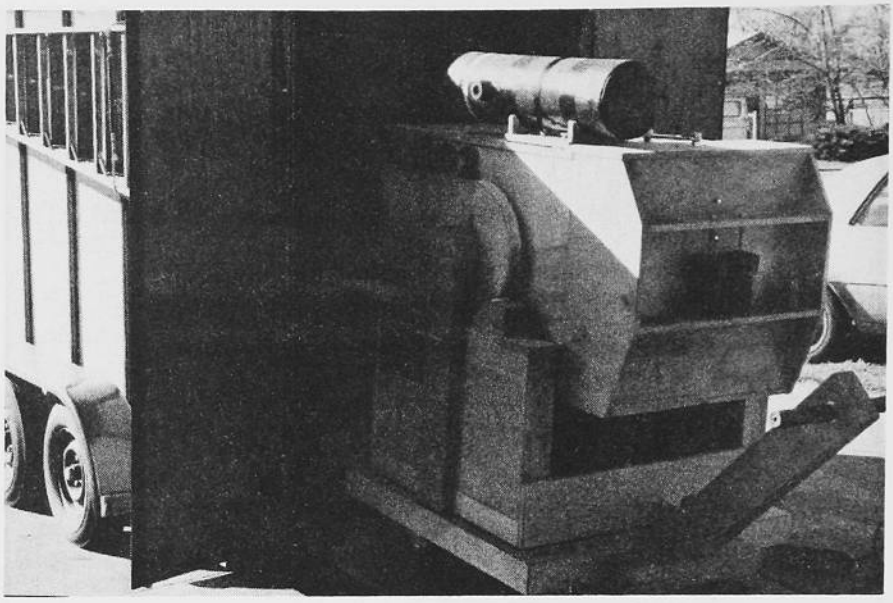
Our system involves leaving the scope assembled and electrically winching it in and out of the totally enclosed trailer. This saves setup time. For instance, our 24-inch can be set up and ready to observe in fifteen minutes from the time the car's ignition is turned off. Nightly recollimation problems are also avoided.

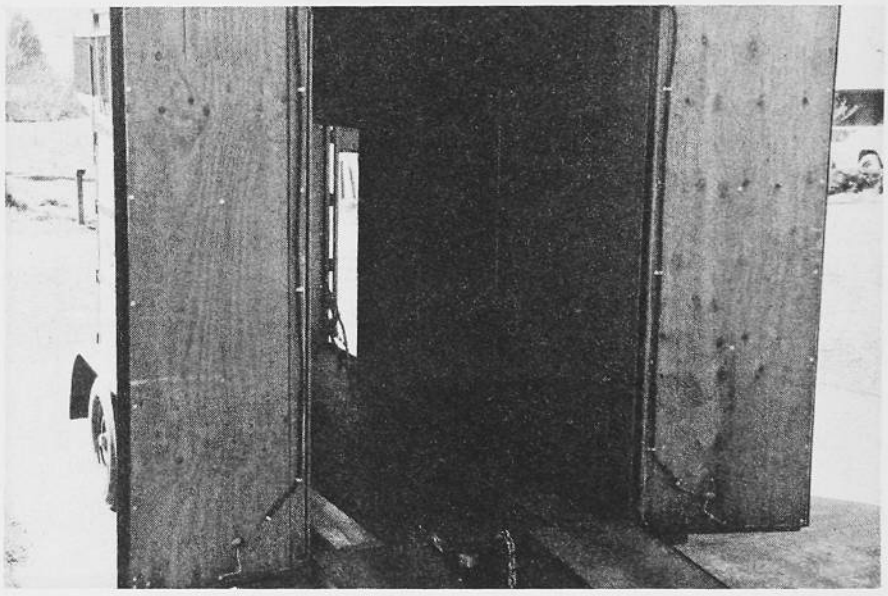
The telescopes have their own tires; one telescope uses small automotive tires to move outside the trailer. With one of the trailers the back door serves as a ramp. Because so little back-breaking effort is required, we believe this results in the scopes being used more frequently.

Books and atlases are carried in racks and it's even possible to sleep underneath the telescope's tube. Red lighting is used in the interior.

We advocate making the trailer. It's not all that hard and it's cheap. The trailer should be made big enough for all the gear that's inevitably needed. And with a totally enclosed trailer the scope is better protected from accidents. Tandom axels are used for rideability and tracking while pulling. Electric brakes are not used because of the danger of losing control on icy roads. Three-quarter-inch exterior plywood is used for the floor and 1/4-inch plywood for the walls with galvanized metal for the roof. The main frame is 2-inch by 3-inch box steel with 1-inch by 1-inch box steel for the vertical side ribs.

The trailer that holds the 24-inch is 4 feet wide, 12 feet long, and 6 feet high. Side doors on each side near the front are important points of access into the trailer. The total weight including scope runs about 1,500 pounds. A 12-volt deep-cycle battery placed on the outside front of the trailer provides power for lights, the telescope, and the winch. And for extra visibility at night and just for looks, lots of running lights





are used. Anyone interested in more details please feel free to contact us.

Mel Bartels
5064 "E" Street
Springfield, OR 97478

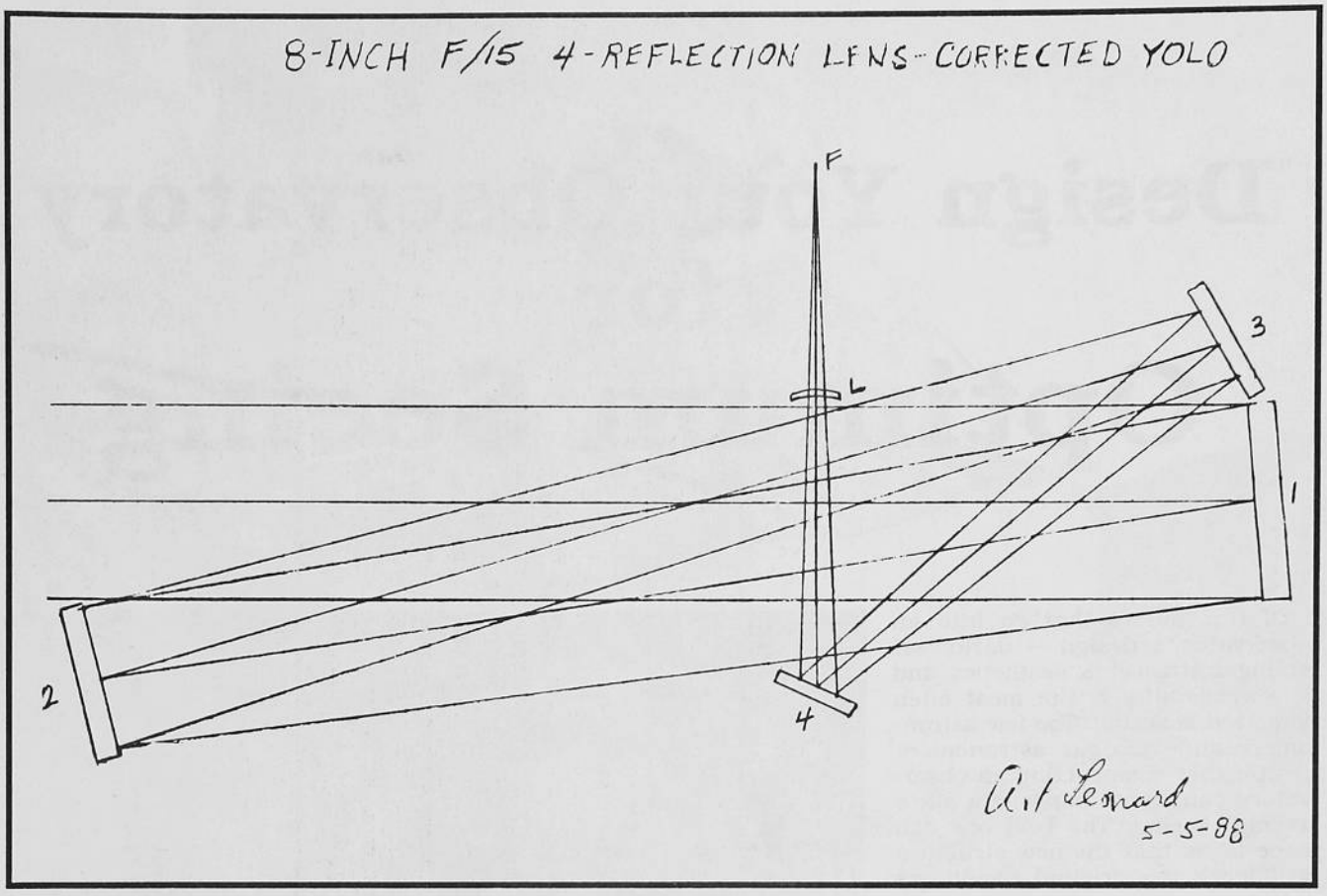
Rob Adams
1361 Lawnridge
Springfield, OR 97477

Don't Forget the Ronchi Star Test

Dear Richard/ I figured and tested all my optics using the qualitative star test and a good Ronchi eyepiece of 250 lines or more. Unlike the lengthy qualitative method described by Dick Suiter, the null test applies not only to Newtonian mirrors but to *any* optical systems, and the results are always interpreted the same way, regardless of the system tested.

If amateurs are to learn a simple and universal method of testing optical systems, it should be the null test. Caustic, Hartman-Dall, and other tests are for advanced perfectionists. A star-tested optical system, which, at its focus, shows three straight Ronchi bands all the way to the edge and no zones or roughness, can be considered as good as the atmosphere will permit. Such results indicate that the converging wavefront is, for all practical purposes, spherical and can hardly be made better. Everything else is academic.

There is a point at which theory ceases to apply to reality and where detectable errors cease to be significant. Amateurs should test their optics, regardless of make, and they should test them easily and effi-



ciently. There is hardly anything simpler or easier to use on any optical system than the star Ronchi test.

Unlike the Suiter article (which took no less than *sixteen* pages!), the null test can be described on a single page. I have figured a 6- and 10-inch mirror using the star test. Both mirrors show some turned edge under the Foucault test, yet the star test is perfect, and so are the crisp Airy disks under high power.

Mladen Vranjican
232 Carrie Drive
Franklin, VA 23851

C10 Wisdom/Info Needed

Dear Sir/ Our club is having problems with a 1967 model of the Celestron C10 telescope, and we are requesting assistance from your readers. The telescope is a C10 SCT with an aperture of 10 inches, f/13, serial number 1967-65, and was obtained by our community as part of a centennial project for our local school.

The site was not well used or cared for until the formation of our club in 1985. The lack of attention during this period has taken a toll in equipment effectiveness. The optics of the telescope remain acceptable, but the balancing, clock drive mechanism, and original components have been altered enough to substantially affect the use of the instrument.

Our only option is to repair our telescope. We would appreciate any information your readers might have concerning the C10 or any photos that describe proper configurations of its accessories. Thank you for your assistance.

President
Athena Community Astronomy Club
P.O. Box 2500
Summerside, P.E., Canada
C1N 4L9

-- I trust that some of TM*'s readers will be familiar with the C10 and will help these Prince-Edward-Islanders get their scope back in shape.*

Software Wanted

Dear Mr Berry/We are looking for IBM compatible software on 5-1/4-inch diskettes, for computing optical systems and for general astronomy. It's hard to get this software here in Holland. Please, if there is somebody there who can help us, please get in touch.

C. Simons
Stichtung Sterrenwacht Saturnus
Frans Halsstraat 4
1701 JL Heerhugowaard
The Netherlands

—There is so much public domain astronomy software around these days, and so many interesting databases (such as Steve Coe's Arizona Database of 10,600 deep-sky objects in epoch 2000) that I expect you to be flooded!

Yolo Warping Harness Gone!

Hey Dick/ Look, no warping harness! I obtained a spectacle lens and tested it for optical quality. It's okay. For a telescope this size it does the job every bit as well as one of my warping harnesses, and all for $7.00.

Arthur S. Leonard
740 Elmwood Drive
Davis, CA 95616

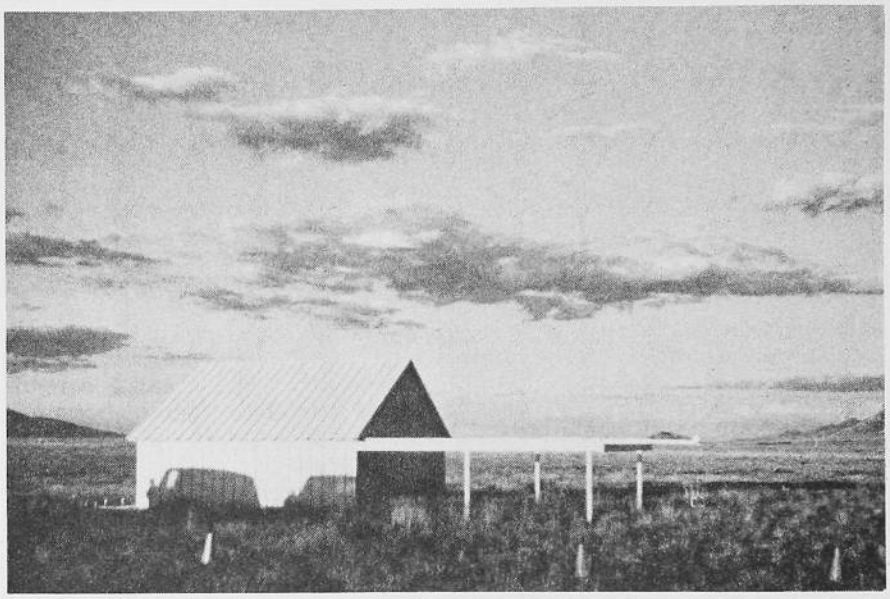
—At RTMC, Art told me that in order to avoid anamorphic distortion of the image, the lens should be as far from the focal plane as possible. I've substituted one of his current designs for his original.

Design Your Observatory for Optimum Seeing

Of the factors that go into an observatory's design -- darkness, seeing, instruments, aesthetics, and site availability -- the most often forgotten is seeing. Too few astronomers and amateur astronomers realize that constructing an observatory can never *improve* a site's average seeing. The best one can hope for is that the new structure will leave the original conditions intact.

The term "seeing" describes the steadiness and sharpness of the telescope image. The seeing at a given locale is the result of many factors that ultimately reflect the steadiness of the atmosphere between the telescope and the object viewed. Turbulent air of different temperatures directly in front of the telescope and in the telescope tube itself is usually the most significant cause for poor seeing. Thus, controlling *warm air* is ultimately the most important factor in observatory design.

It is imperative to appreciate the thermal characteristics of the materials used in observatories and their environs and then to design the structure and surroundings so they do not trap a large amount of heat during the day and then release it all night long. Heat trapped during the day must be released quickly after the observatory is opened up at night. "Heat waves" (i.e., plumes of warm air) radiating (i.e., convecting) off the telescope, the observatory building, and the surrounding grounds produce a wavy turbulence that renders good seeing impossible. If not properly controlled, this turbulence severely compromises the usefulness of the facility.



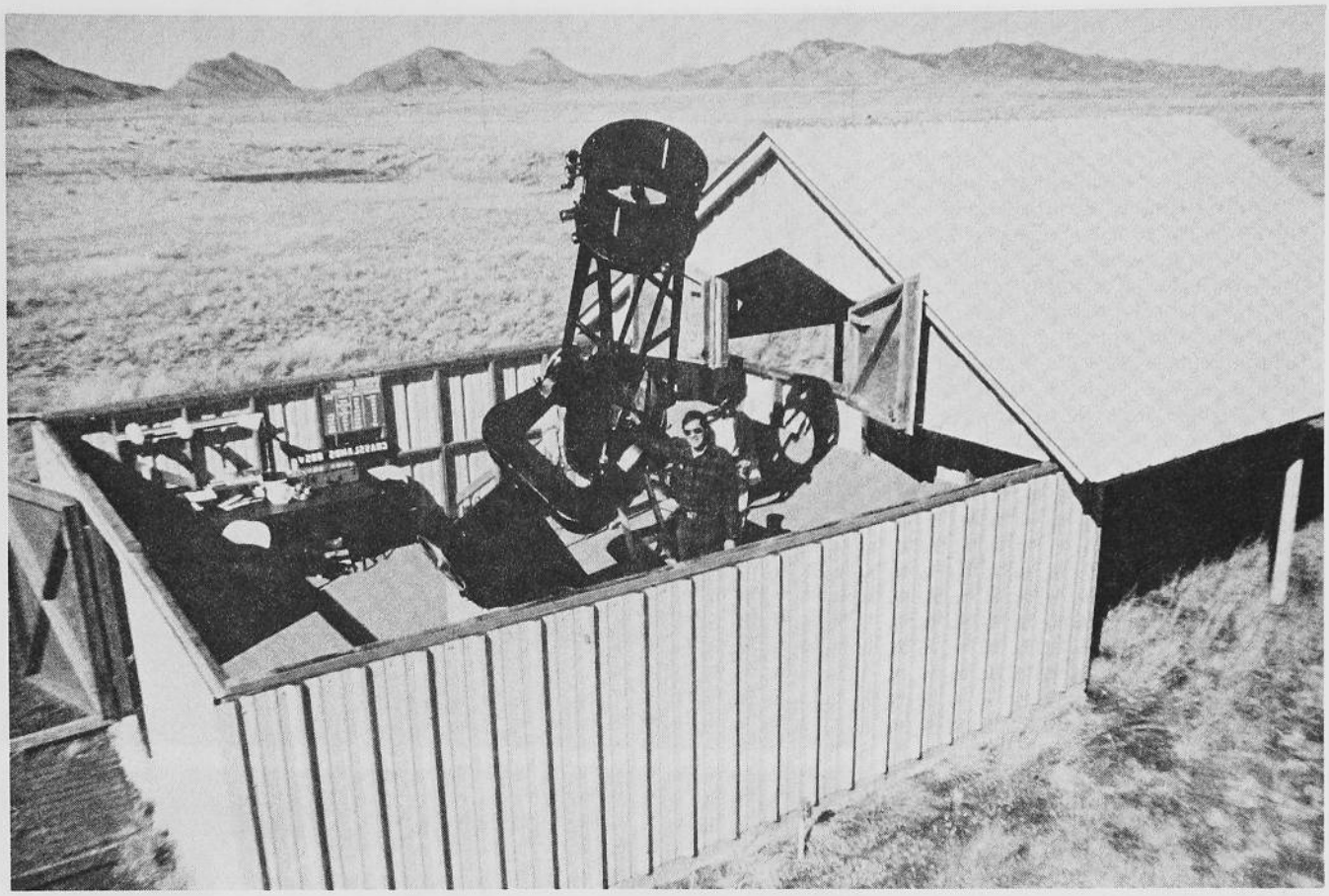
Grasslands Observatory in southeast Arizona was designed to provide optimum seeing for a 24-inch telescope. Key is low heat uptake.

Guidelines for Observatories

Consider seeing in picking and evaluating an observatory site. Amateurs often spend considerable time evaluating the darkness of sky locations at a given site, but they often do not have time, money, or sophistication to evaluate the seeing conditions too. But a very dark site with poor seeing may actually be worse for the observatory in the long run than a site with brighter skies but better seeing.

One can optimize seeing by avoiding locations that encourage turbulent air masses; by trying to situate in flat, grassy areas or hilltops with little or no adverse wind flow; and by staying away from barren sand and rocky areas. If possible, spend time viewing the Moon and planets from different locations to see which areas consistently give the the best seeing.

Never place priority on aesthetics and accessibility of a site at the expense of seeing. Avoid materials that absorb heat and build up large thermal masses. Buildings constructed from brick and cement blocks, particularly if they are surrounded by concrete or asphalt walks or parking areas, may present a pleasing appearance but rarely permit good seeing. Heated



This bird's-eye view shows beige-colored aluminum siding and low-thermal-mass walls of the observatory – and the 24-inch telescope.

air rises from the brick and asphalt all night, and often the telescope never reaches a steady temperature and never looks through a stabilized air mass.

If an observatory sits on top of a garage or on the roof of a house, there may be radiations of heat off surrounding structures for hours. Grass and low, open shrubbery cool rather rapidly, while barren ground, rocks, or gravel often give off heat for hours. Even vehicles parked too close to the observatory -- because of engine heat -- can make a notable difference in local seeing.

Although observatory domes are more pleasing to the eye than roll-off roofs and offer a much greater wind protection, they can make for quite destructive seeing. A constant chimney effect occurs as warmer air leaves the building through the slot. Two-story buildings with large spiral staircases are aesthetically pleasing and elegant, but care must be taken so that the room under the observing room does not trap heated air and leak warm air past the telescope at night.

Dome seeing can be overcome, or at least reduced, by constructing the dome out of light, reflective materials, by having a relatively wide opening, and by taking care to open the building and dome up an hour or more before an intended observing session.

Completely open air observing is best for seeing because the telescope reaches thermal equilibrium with the night air more quickly. However, this is not practical for a large telescope that needs a permanent site and protection from the elements. In designing an observatory, maintain the principle of keeping the observatory building to a low thermal mass and keeping any heat sources well away from the telescope.

If the observatory is constructed from brick or cement blocks and sits near asphalt walks or driveways, the heat given off by these substances may hamper observing for hours even though the telescope itself reaches rapid equilibrium with the night air.

Roll-off roof observatories are good because heat can rapidly escape from the building and telescope. Roll-off roofs are also less expensive and easier to build than domes, although they become difficult to manage for buildings much bigger than twenty feet square because the roof becomes too large to easily prevent sagging and its weight makes it more difficult to be moved.

Roll-off roofs are also impractical for observatories built on top of garages, homes, or other buildings. Such observatories are particularly prone to suffer thermal mass problems from the adjacent buildings. They may work very well if the lower level can be opened up to allow heat to escape and permit rapid equilibrium with the night air temperature or if the nearby roof and other materials do not store large amounts of heat during the day and radiate it at night.

An Observatory That Works

We have recently built a large, roll-off roof observatory that houses a 24-inch Newtonian Cassegrain telescope. This building was designed to avoid compromising seeing. It is situated on twenty acres of grassland in a remote dark

sky location in southeastern Arizona.

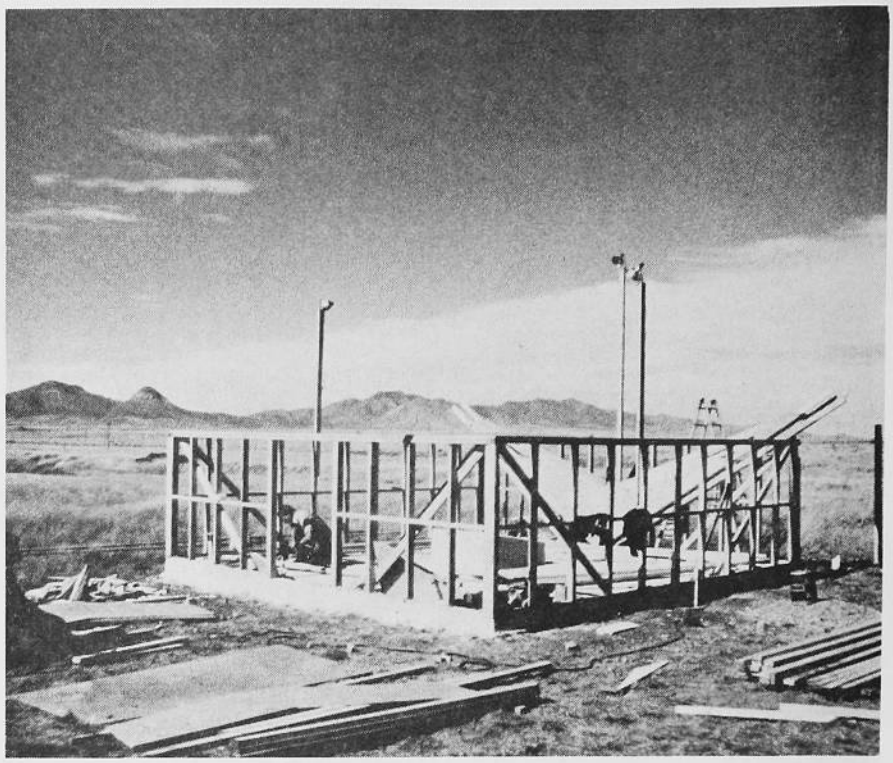
The flat, grassland terrain generally has calm conditions after sunset, with little wind and little heat given off by the grass and low shrubs and weeds. The grass is periodically trimmed around the observatory to prevent a fire hazard during the dry months. No noticeable heat radiates from the ground at night. A small parking area forty-five feet away from the observatory keeps automobiles far enough from the telescope so that heat waves rising from the cooling engines do not bother the observing.

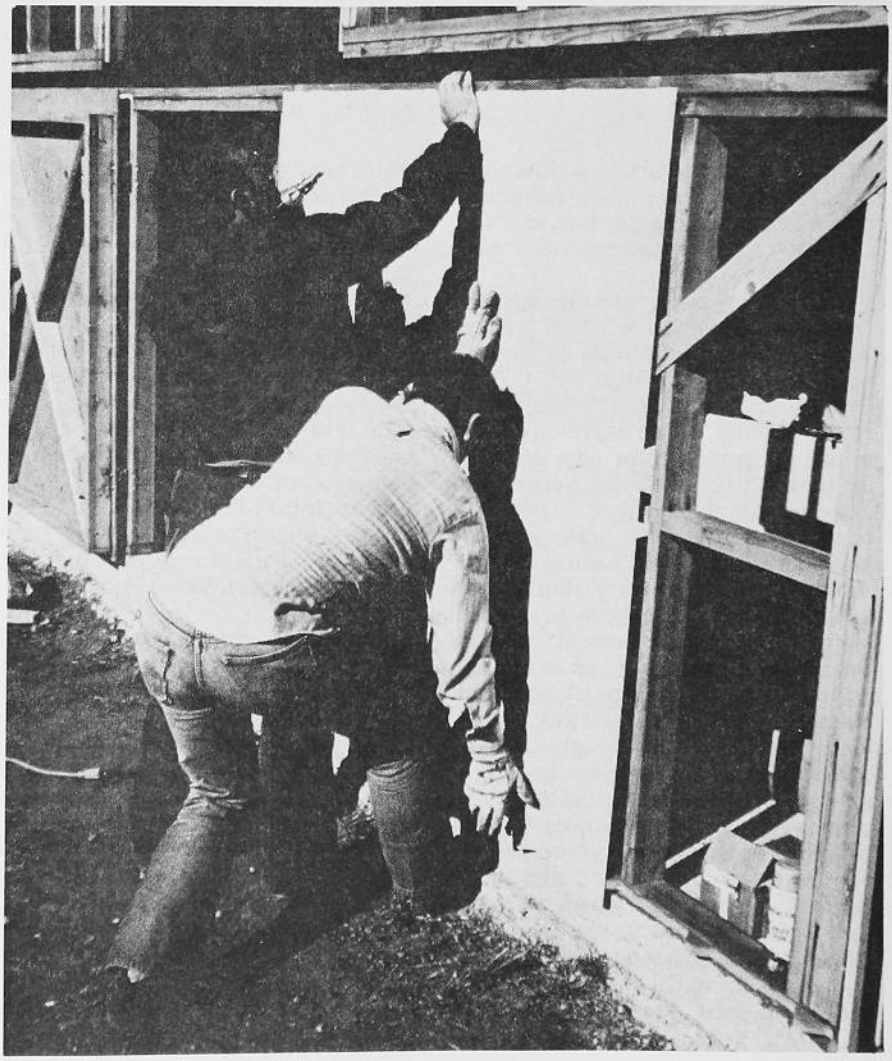
To counter the heat build-up from the intense Arizona Sun, the observatory walls and roof consist of a beige reflective metal siding covering a wood frame. Our sliding was purchased from Paragon Steel Structures, Inc., 7065 West Allison Road, Chandler, AZ (602) 961-0777, but similar siding should be available from other suppliers in cities around the country. It consists of individual overlapping Industrial I. R. rib panels that are 39.25 inches wide, with a 36-inch coverage, and a 2- to 3-inch overlap between contiguous panels. The panels come in various colors. Beige was chosen for the observatory because it is a reasonably reflective color and blends well with the surrounding grasslands, which gives a more pleasing appearance than white. The panel finish is guaranteed to last for twenty years and needs no painting. The panels have a fixed width but can be ordered precut and trimmed to any length. It is recommended that they be precut by the supplier because they are rather difficult to cut with a typical home power saw.

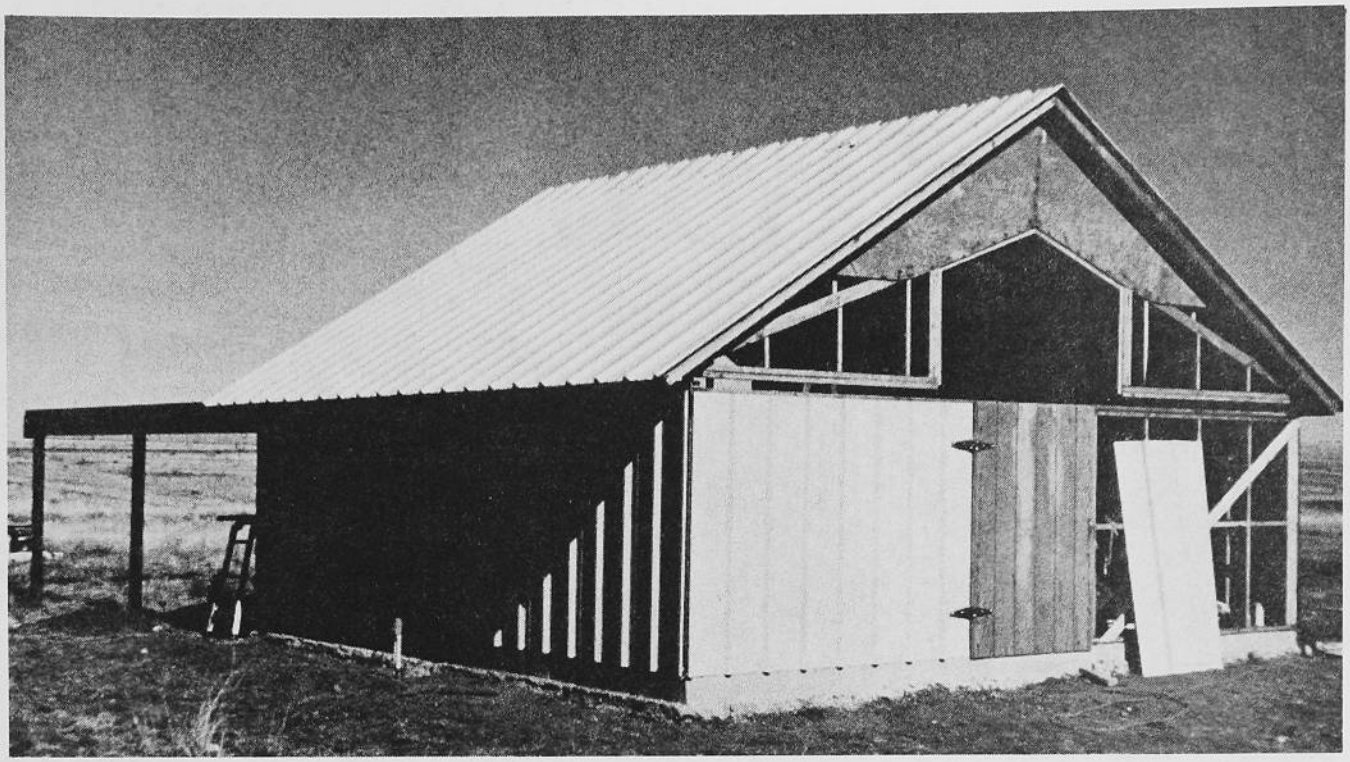
Self-tapping and self-sealing stitching screws with hexagonal heads attach the metal panels to the wooden wall and roof frames. Foam inserts and silicon sealer close air gaps where the panels overlap and where the panels attach to the floor and top of the wall.

The pier consists of steel reinforced concrete four feet by seven feet deep. The floor is separated from the pier by one inch of sand. It surrounds the pier to prevent vibration from the floor being transmitted to the telescope. The floor is six inches thick. The pier and flooring were poured by Patio Pools, 1440 Fry Boulevard, Sierra Vista, AZ 85635, (602) 458-9291.

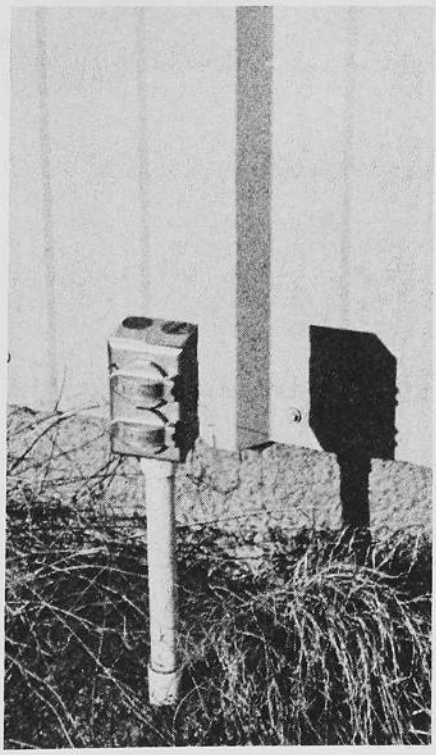
Both the floor and the pier are covered by Kool-Deck, a patented

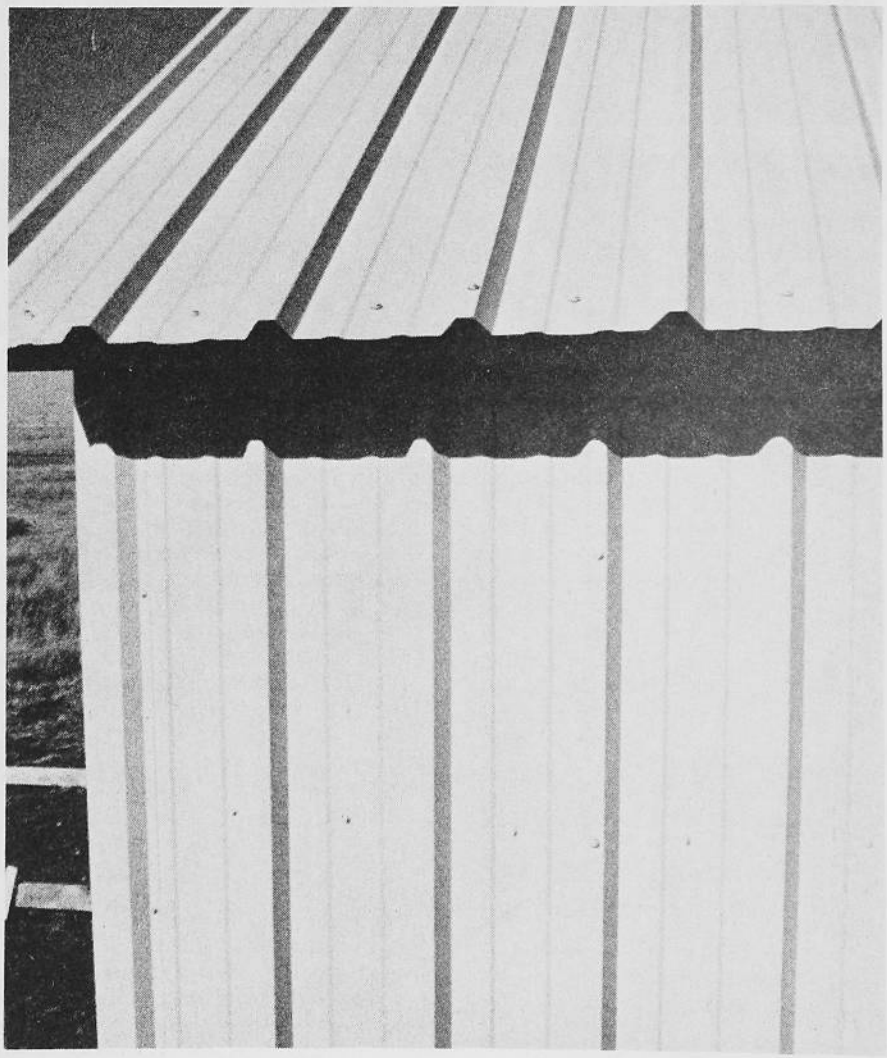


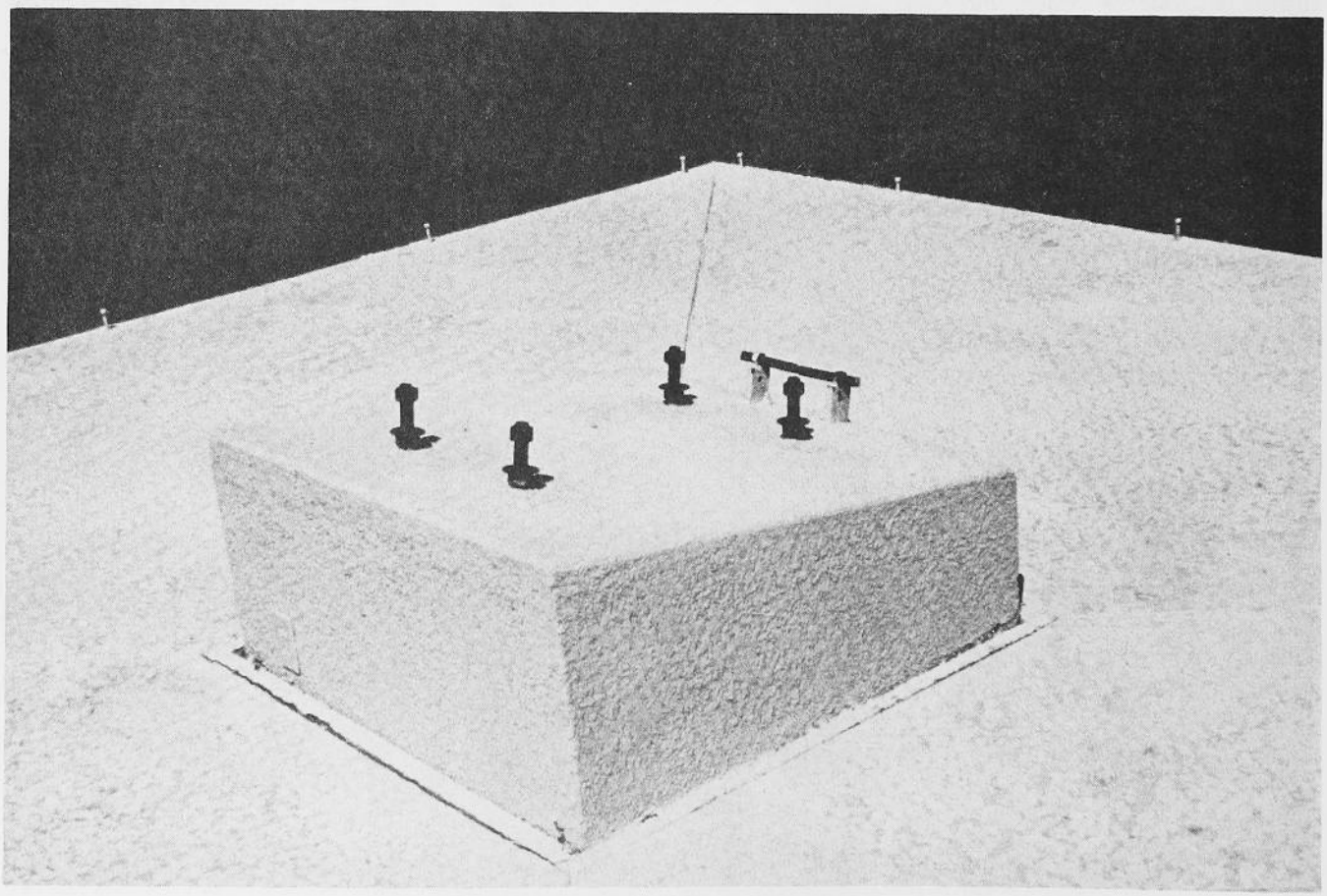




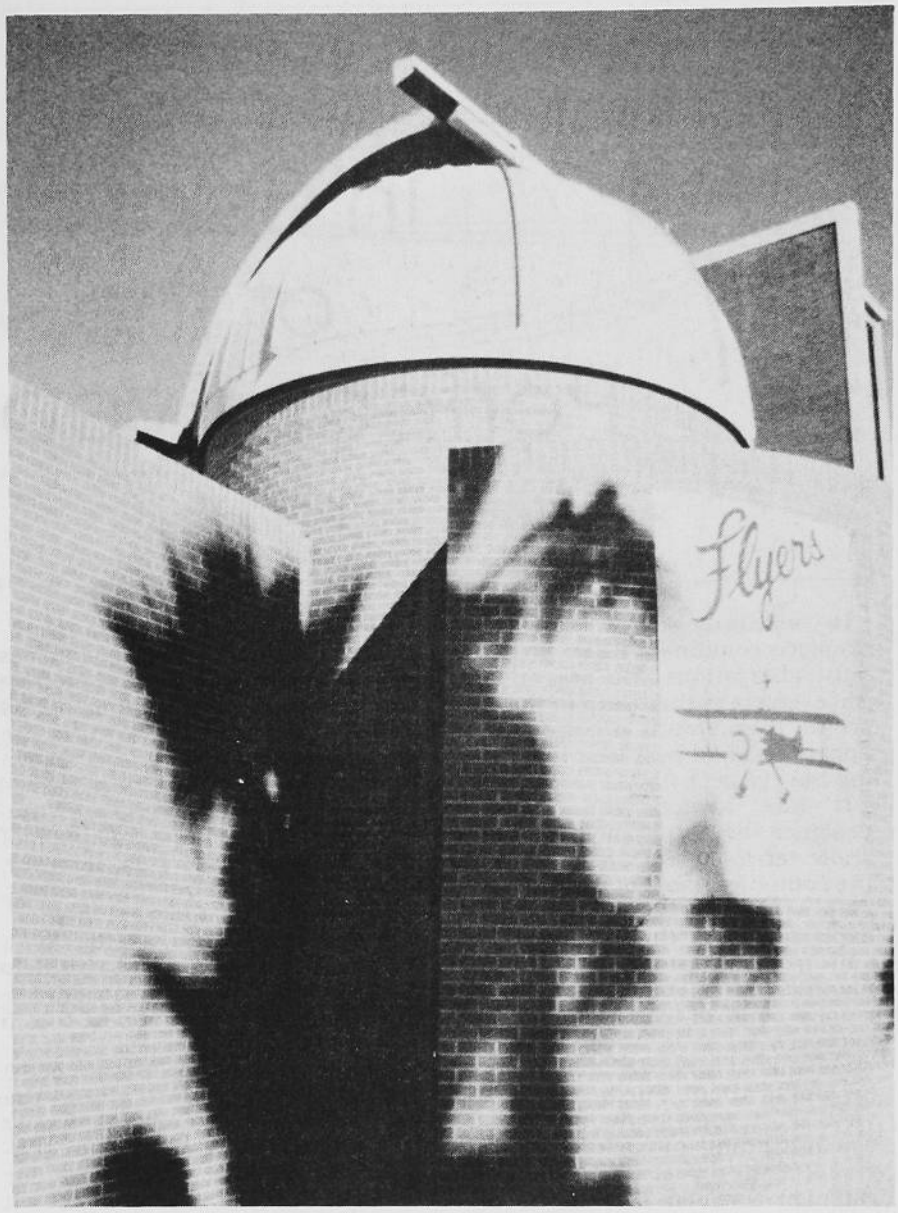
Installing beige precut aluminum siding with self-tapping and self-sealing hex-head screws to the stud-wall construction was quick and relatively easy. The three-foot panels were sealed at the edges, and filled with foam inserts at top and bottom. Panel is guaranteed for a twenty-five-year life and needs no painting. Most important: it doesn't hold heat.







After pouring the pier and floor, the concrete was covered with Kool-Deck, a topping that keeps concrete from getting hot during the daytime.



substance used in pool decks to prevent burned feet in the midday Sun. Kool-Deck is mainly popular in Texas, Arizona, and parts of the South. Most pool builders should be able to purchase it. Kool-Deck is a heat reflective topping designed specifically for concrete, especially at exposed surfaces. It keeps concrete much cooler because radiant heat from the Sun does not penetrate into the concrete. Even though there is an enormous mass of concrete in the observatory floor and pier, there is little heat storage. Kool-Deck is not popular in the more northern parts of the United States because it is less necessary to protect one's feet from concrete burns and it is not durable in harsh winter conditions. It should last well enough on the floor in an observatory because it will not be exposed directly to the elements.

The Kool-Deck does make an amazing difference in the temperature of the observatory building. The building and surroundings are sufficiently well optimized for temperature control that within thirty minutes after the roof has been rolled off for night viewing, the telescope is acclimatized to the outdoor air temperature. During early evening observing the observatory door is left open to prevent pooling of hot air capped by outside cooler air. The seeing is limited by the night sky seeing, not by heat waves coming off the building.

Indoor/outdoor carpeting on the floor gives a pleasing, aesthetic effect and is also easy under tired feet. We recommend carpeting as a barrier to prevent small amounts of caustic substances on the concrete floor and Kool-Deck covering from slowly stripping the reflective coating on the telescope mirrors.

The roof is twelve feet high to accommodate the telescope. The peaked design allows rainwater and snow to wash off without accumulating. Because the observatory is large and has a heavy peaked roof, we have to use small boat wenches to roll the roof on and off.

For Optimum Seeing, Don't Copy the Pros

Maintaining the excellent seeing conditions of the best sites has to be a very high priority in housing the very largest telescopes. Excellent seeing is critical for almost all sky-limited research problems. Much cost goes into selecting and developing prime observatory locations and optimizing telescope optics and instrumentation. The design for the telescope housing should be a part of this process.

Unfortunately, many existing professional telescope housings are far from optimal. It is not wise to copy a design of most professional observatories because many of them are poor thermally. This is particularly true of smaller observatories constructed in conjunction with university teaching facilities, planetariums, and science museums. Very often aesthetics and availability are the prime considerations and no thought has been given to astronomical seeing.

The overall goal of observatory design is to minimize warm air and turbulence in the structure in or near the telescope itself or in its light path. For good viewing and good astronomy, do not place aesthetics ahead of designing for good seeing. Use your head and build a structure that doesn't get hot and doesn't hold heat.

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In Search of the Perfect Eyepiece

In virtually every telescope-eyepiece combination the predominant aberrations you see arise in the eyepiece rather than in the telescope. If you want a better visual image, you had best look to improving the eyepiece first.

It has always amazed this designer that while most eyepieces show terrible field aberrations on the computer, most of them actually give a very pleasing image. The explanation for this is that unless you are using the highest possible magnification, your eye cannot resolve many of the flaws. Therefore it makes sense to understand how much quality you need for a particular application. Furthermore, the virtues of wide-angle images are worth trading off against readily visible field defects, as is done in common binoculars.

Some of the newest designs, such as the Pretoria coma-correcting eyepiece, not only correct their own flaws but eliminate the residual aberrations of the telescope mirror itself. Such eyepieces correct SOME of the residual aberrations in a Schmidt-Cassegrain objective, but the improvement is not complete. It should be appreciated, however, that these eyepieces are NO WORSE than the best of the ordinary designs and so may be used freely on SCTs.

An objective-eyepiece combination can be thought of as a telescope with a special microscope (eyepiece) magnifying the telescope image for the observer's eye. It is a widely used rule that a telescope requires about 50 power per inch of aperture to see the finest detail in an image. For those using a microscope, a similar rule is that unless the power is high enough to produce a 0.5mm-diameter exit pupil, not all detail is visible. The two rules are equivalent, but it has been shown that the smallest spot ever formed on the retina subtends about 2 arcminutes, which gives a resolution of about 1 arcminute. This, however, occurs for a 2.3mm pupil diameter, not 0.5mm. What's going on here?

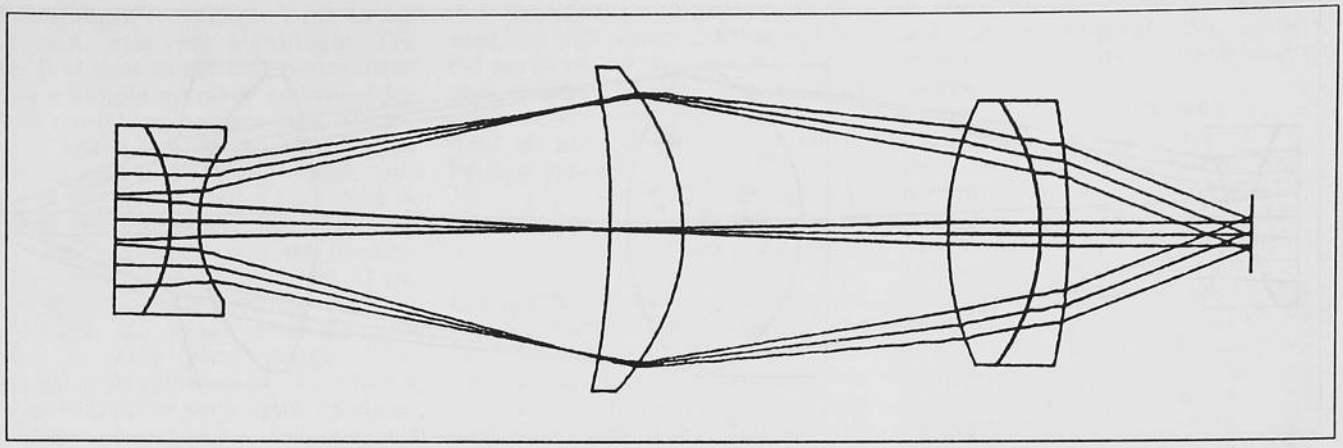
An examination of the letters on a Snellen eye testing chart can help in understanding, because the letters are constructed on a 5 x 5 matrix, with each element subtending 1 arcminute at a distance of 20 feet. If you have 20/20 vision, the notation means you can just barely read the line whose elements subtend 1 arcminute. If you have, for example, poorer vision, 80/20, it means that the line you can read would have elements subtending 1 arcminute if viewed at 80 feet. But, given the choice of reading a newspaper with the smallest letters just visible, or the ones on the 80/20 line, you might well prefer the larger letters.

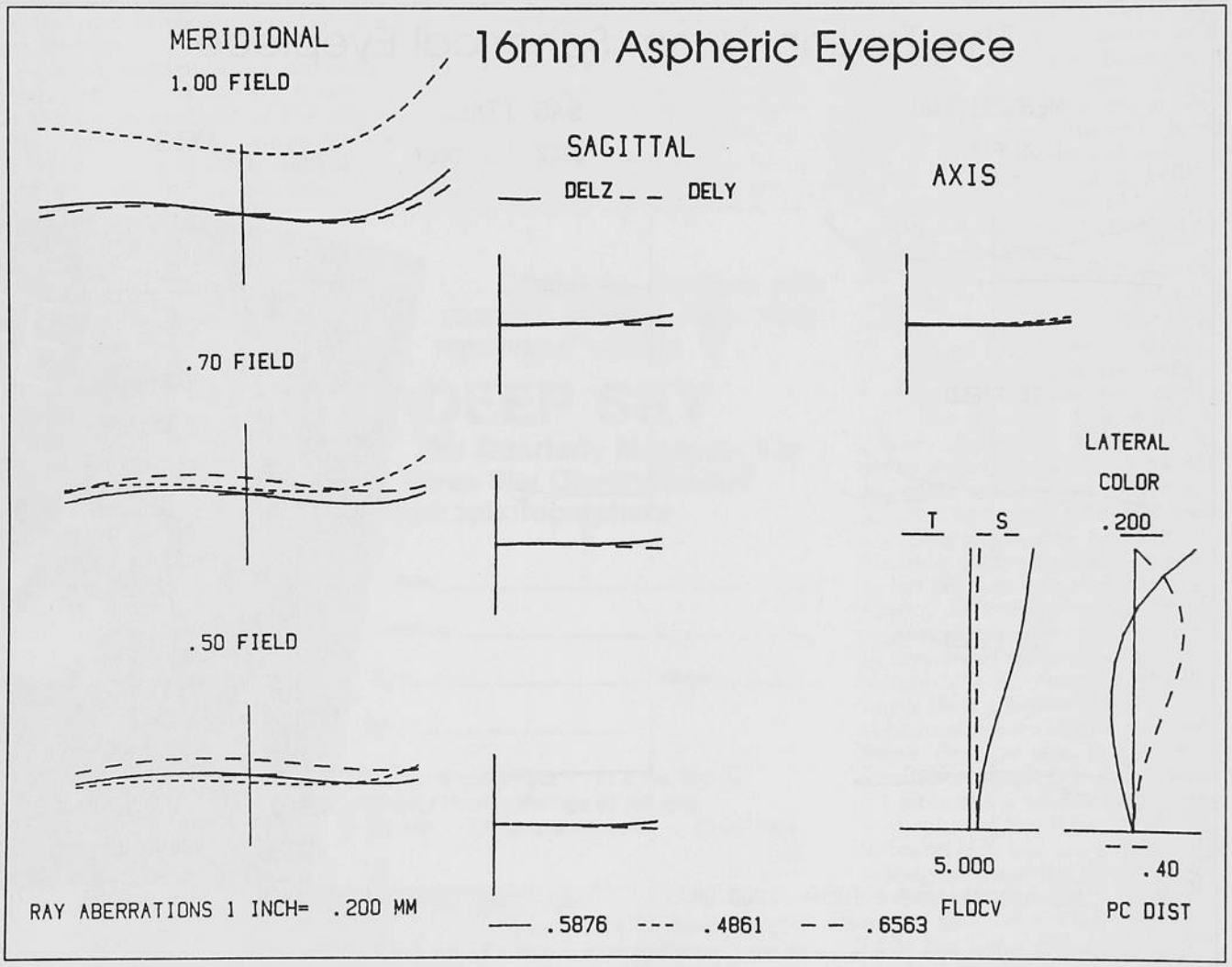
The point is that an observer always magnifies the image more than the minimum *just barely* required to resolve the detail he wants to see. He magnifies it until that detail is *readily* visible. However, he doesn't go beyond a certain point at which the restricted field of view becomes a handicap or to a pupil diameter where the image is too faint to activate the color sensing mechanism in the eyes' cone vision. Needless high magnification is termed EMPTY MAGNIFICATION, because it produces no additional improvement of any sort.

An empirical rule I've found useful in determining the tolerable aberrations in an eyepiece is based on the previous line of thought. Suppose we say that we need a 0.5mm pupil to see all the available detail. We can then argue that for a 0.5mm pupil, we may tolerate 1/4-wave image defects in the wavefront. If we have a lower power eyepiece, say one giving a 2mm exit pupil, then the allowable aberrations can rise to 1 wave.

If we go to a very low power eyepiece, say one giving a 6mm exit pupil, not uncommon for deep sky viewing, we can tolerate 3 waves of aberration. And if we are willing to permit some visible deterioration of the field image, which of course we do with some very wide-angle ordinary eyepieces, the tolerances become much larger. It surprises some people to learn that the blur at the edge of the field of a typical Erfle eyepiece produces an astigmatic blur larger than the apparent size of the Full Moon as seen with the naked eye.

For an optical designer, this means that the wave optical quality required in a low-power eyepiece is greatly relaxed. Put another way, low-power eyepieces can be simple in design, provided we don't take up the slack by demanding a wider field of view. Within the common realm, however, Ramsdens and Kellners give good performance at low power, but Plossls, Orthos, Konigs, etc., are *de rigeur* at high power. There are, of course, other considerations, such as ghost

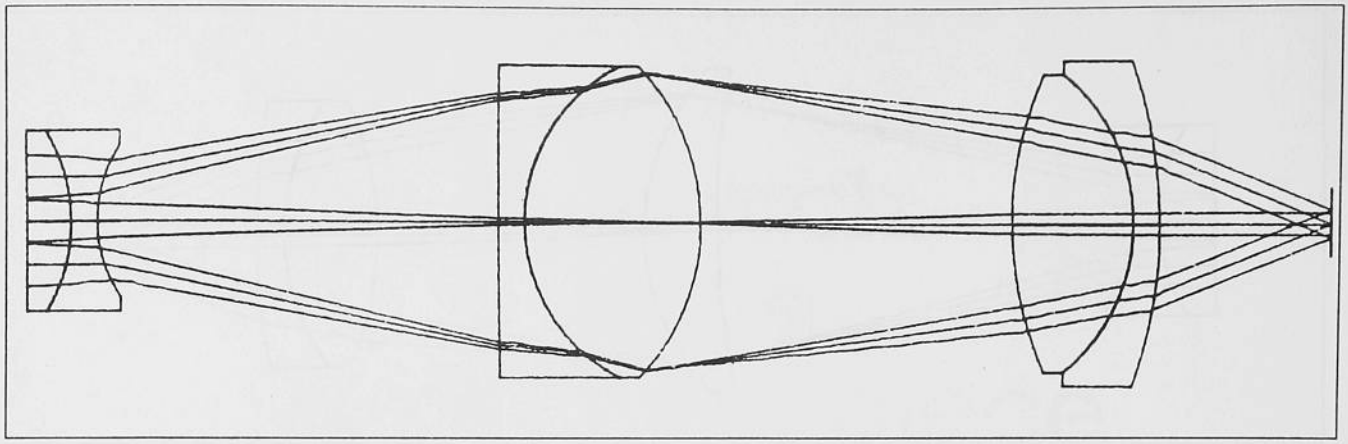


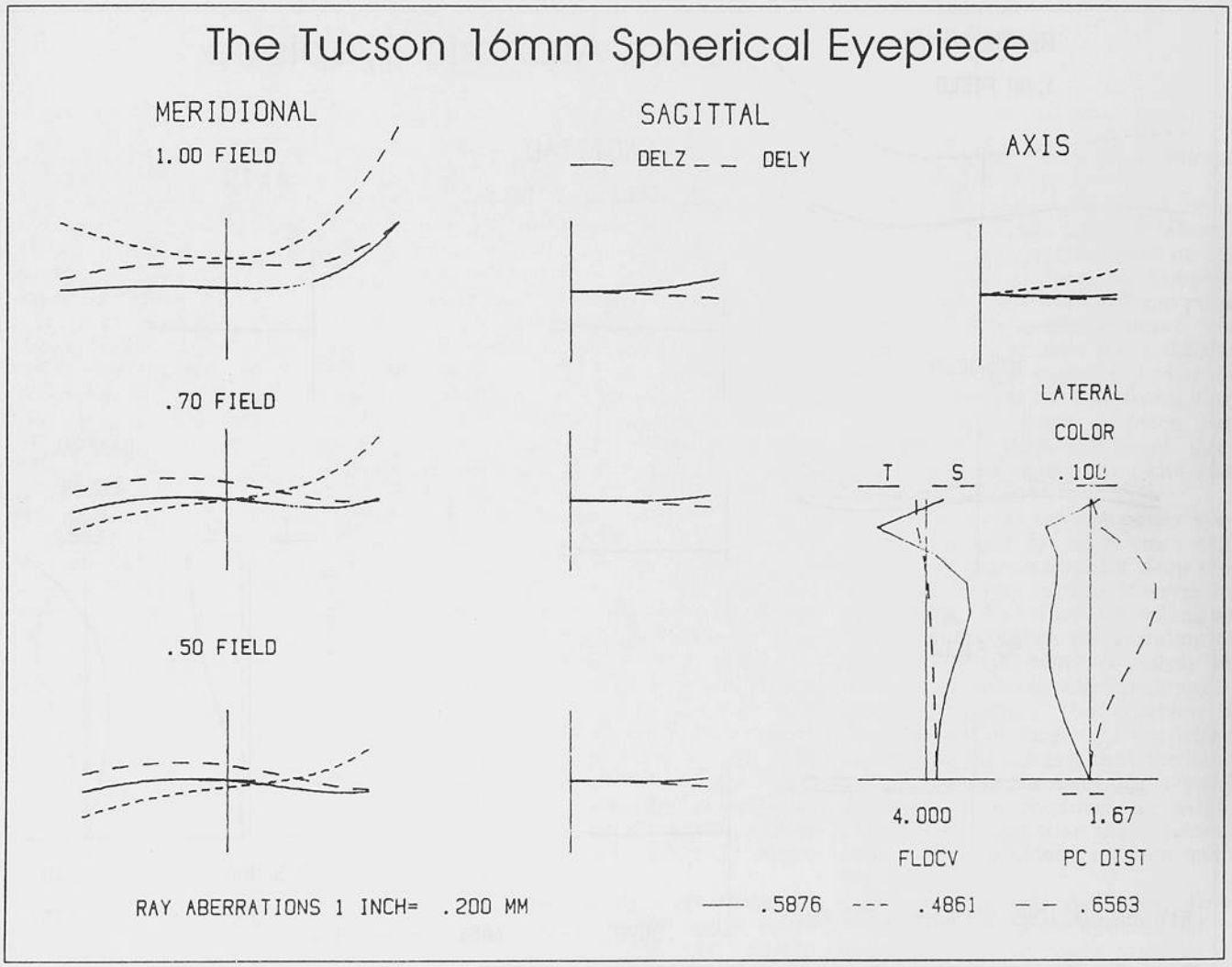


images within a particular class, but the principle is the point here.

New generation eyepieces, such as Naglers, Meade Ultra-wides, the Clarke, the Pretoria, and others, offer uncompromising image quality. Curiously enough, this improvement in quality enhances contrast and reduces eyestrain beyond what might have been expected by the proportional magnification rule we have described. Although our rule assures sufficient resolution, aberrations of the magnitude we have described in conventional eyepieces significantly reduce contrast at the readily visible spatial frequencies at low power.

A quick look through an eyepiece does not produce a complete picture of the eyepiece's overall capabilities. It will reveal whether the eyepiece has glare or ghost images and if its eye relief is sufficient to make use of its wide apparent field of view. Lateral color and a chromatically hued field stop are factors quickly ascertained. But resolution and star blur size, in particular, are poor tests of an eyepiece's perfor-





mance. On the other hand, for many kinds of work, especially deep-sky viewing, simple eyepieces are quite acceptable.

In thinking about this, I was prompted by curiosity to enter a design for a 16mm coma-corrected eyepiece I had previously computed. In trying to optimize this design, I found that it was virtually impossible to reduce spherical aberration of the pupil except by using extremely high index glass, which is costly and not an elegant solution to the problem. It made little difference when I simply added more elements to the eyepiece cluster as opposed to the Barlow section. The original design was an achromatic Barlow plus a 3-element Kellner.

Reasoning that the pupil aberration must be attacked directly, I put an aspheric (ellipsoid) on the convex surface of the plano convex field lens, and then let the computer program vary everything else to optimize the design. Not only did this correct the spherical aberration of the pupil, but it also corrected the

distortion of the image. That, in my opinion, was very significant. For the first time in my experience, here was a simple eyepiece corrected for field curvature, astigmatism, distortion, coma, spherical aberration, lateral and longitudinal color, and spherical aberration of the pupil. A check for chromatic aberration of the exit pupil revealed the aberration was small and tolerable. Thus, if it were possible to make such an eyepiece, the eyepiece would produce a very good image. (The aspheric element would make this a very difficult or very costly eyepiece to make.) Incidentally, this eyepiece was designed to be used with a Newtonian and is coma-corrected like the Pretoria.

Because aspherics are not easy, computer runs were made to derive aspherical equivalent of the conic lens. Unfortunately, it turns out to be a very strong doublet, and both it and the aspheric version also have the practical problem that the field lens (first lens after the Barlow element) is virtually in focus, to produce a possible dust and ghost problems. Nonetheless, the point is that a complex field lens, be it spherical or aspheric, seems to be the key to producing an aberration-free eyepiece. I would like to encourage others to examine this principle to find a practical design.

The eye relief is 25mm on both these designs, experience has shown me, is right, because I must wear glasses for astigmatism. This allows eyeglass wearers to see the field stop without having to move the eye from side to side.

No design specifications are given because I am presenting the diagrams and material to explain a principle. The glass types are SF4, SK16, and SSK2.

These designs are not extremely wide field designs because the constraints I imposed (simplicity and the use of low-cost glass types) impose an apparent field of about 42 degrees. However, this should be acceptable for the serious observer because the images in this field will be ideal and, as I pointed out earlier, will result in better contrast and easy of viewing because the eye is more relaxed.

Aspheric binocular eyepieces have been made in Germany, but I have never seen an aspheric used as it has been used in the present design. The use of an aspheric eyepiece to correct distortion is well known, but not for pupil aberration as well as all the others. Now add the possibility of replacing the aspheric with optics having spherical surfaces, as the Houghton lens corrector can replace the Schmidt aspheric corrector plate, and a new field of high definition eyepieces become possible.

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Tucson, AZ 85716

ED NOTE: It has long amazed me that the astronomical observer has been so particular about the accuracy of his objective lens or mirror but virtually indifferent to the part that allows him to see what the telescope will show -- the eyepiece. Back in the early 1930s amateurs were glad to find low-cost eyepieces from World War I surplus optics with which to observe. Those who had the money to buy these Kellner or Erfle units were looked upon as "king of the night," and others begged to borrow their equipment.

After the end of World War II many fine surplus eyepieces

If you want a better visual image, you had best look to improving the eyepiece first.

became available -- improved Erfle, Symmetrical, and Plossl designs. I was quite lucky because my father, in 1935, bought me a 6mm Busch Orthoscopic microscope eyepiece, which he mounted in a 1.25-inch barrel. I still have this eyepiece and, although it is uncoated and shows ghosts when Jupiter or a bright object drifts across the field, it is still one of the sharpest image-producing items in my collection of oculars.

It has always bothered me that in designing eyepieces no one had corrected the coma of a parabolic mirror. It just seems to make sense that, used on a fast mirror, it would present edge images equal to those at the center and be a valuable observing asset.

I mentioned this to many people over the years, but nothing came of it until a friend from South Africa, H. W. Klee, came to the United States and spent 2.5 days visiting with me in St. Louis. In our conversations I mentioned how great a coma-correcting eyepiece would be for the new breed of deep-sky Dobsonian telescopes. A few years later he and his boss at the Optical Center in Pretoria came to the 1985 meetings of the Optical Society of America and, at my request, the Tucson meetings of the Astronomical League.

One of the papers was on the design of a coma-corrected eyepiece, and to my great surprise they presented me with a prototype eyepiece they had fabricated in South Africa and brought with them, one of three in the world at the time.

Others are now examining and marketing similar ideas, but no one to this time been fully corrected eyepieces, such as the one described above. I hope that the principles outlined above by Buchroeder will inspire others to examine the fully corrected eyepiece approach and to manufacture and market these eyepieces. Because it is important to keep costs down and to keep the design simple, the extreme wide- and ultrawide-field must be sacrificed. For a serious observer, this should not be important, because skilled observers always bring the object of study to the center of the field.

The wide-field eyepieces now on the market do not allow an observer wearing glasses to see the field stop, and if the observer suffers from astigmatism or other serious eye aberrations, then he cannot remove his glasses. Eye relief is another problem, because it requires even those without glasses to put their eye so close to the rear element. Their eyelashes will wipe oil and dust on the rear element.

Cleaning will eventually remove even the best coating and lower the efficiency of the assembly. Those designing eyepieces should consider eye relief distances of 22mm to 25mm to allow eyeglass wearers to enjoy their eyepieces and to prevent contamination of the rear lens.

These designs are larger than conventional eyepieces. Some years ago I mounted a 16mm Erfle using war surplus optics lens in a 1.25-inch barrel that was 1.5 inches long; the designs presented by Dr. Buchroeder require barrels 2 inches in diameter and about 6 inches long.

It has been over fifty years since I made and used my first telescope. We're finally seeing high-quality aberration-corrected eyepieces for the observer. I trust that the ideas expressed by Dr. Buchroeder for fully corrected eyepieces will not take another fifty years, because I'd like to be around to see this new breed and look through them.

-- R.E.C.

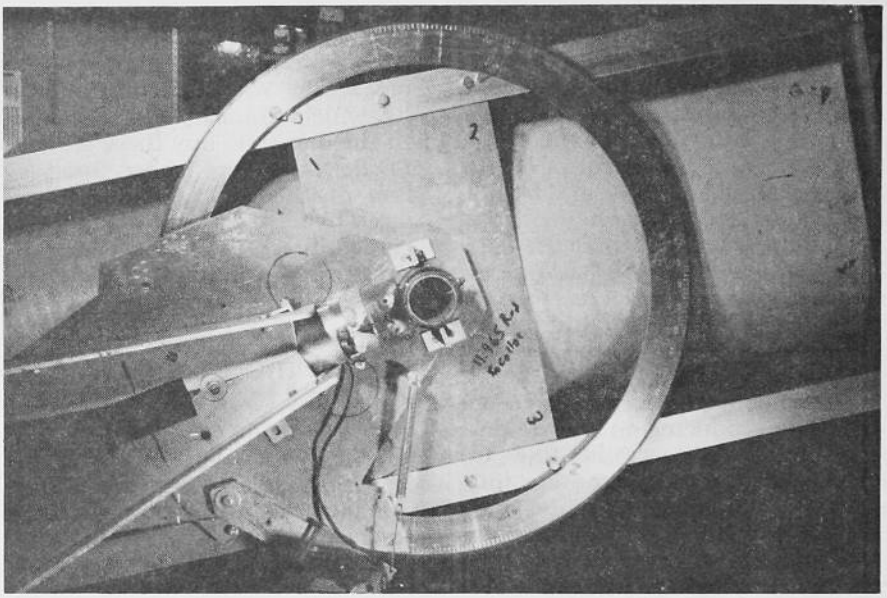
A Method of Making Precision Worm Gears of any Diameter

Because I'm interested in astrophotography, I wanted a precision R.A. worm-gear drive for the 17.5-inch equational I was building. My particular fork design called for a gear approximately 30 inches in diameter. I talked to all the local machine shops in the South Bay with gear-cutting capability, but the lowest bid I received was approximately $2,000 to cut the 3/4-inch-wide 12-pitch gear. Most of the shops thought I was nuts and laughed when I asked for a 359-tooth gear rather than one with 360 teeth.

After about a month of being laughed at, I decided there must be a cheaper and easier way to go and put my subconscious to work on the problem. Amazingly enough, the solution didn't take long. The answer was to use a gear mounted like a starter ring on an auto engine and worm drive the ring gear. I knew this would work very well based on the billion or so gears that have been done this way since the automakers started putting electric starters in cars.

For those of you who are not car buffs, most starter-ring/flywheel assemblies are a mild steel flywheel with a very tough high-strength ring gear heated and shrunk onto the perimeter of the flywheel. Having replaced a number of these starter rings over the past forty years, the same scenario for the R.A. drive I wanted seemed like the ideal solution. In additional, it would only cost 5 to 10 percent of what the gear-hoggers wanted for a similar gear.

Boston Gear Company makes a wide variety of rack gears, so there's plenty of choice depending on your particular design. These may also be ordered in special lengths, which will leave you only one weld to make. After removing the unwanted backside material, roll the rack into a circle and weld the ends together to form a ring.



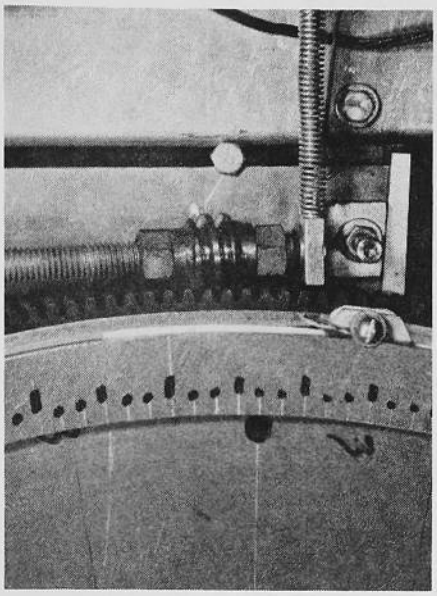
Some recommendations: For steel rack, weld the ring together using a "medium" temperature brazing rod (i.e., a rod with a melting point of 600° to 700° Celsius). Lower temperature rod (450° to 500° C) may not have adequate tensile strength, and the high-temp stuff is hard to use unless you are pretty good at oxyacetelene welding. If you use brass rack, you will have to use the medium or possibly the low-temperature rod, or run the risk of melting the rack.

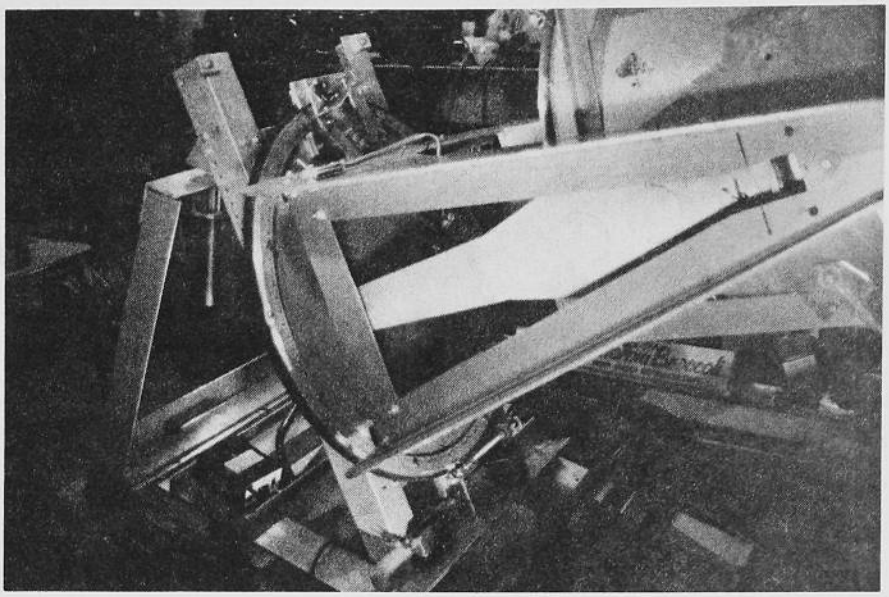
Also with the quartz drives available today, you should probably use some *even* multiple or submultiple of 360 teeth. This will give the proper intervals for measuring R.A. or dec. very precisely and for making setting circles.

Machine off some of the material from the backside of the rack to leave a nice strap that will be easy to roll into a circle. Weld the pieces together through the *center* of a tooth. This will greatly increase the ring's strength under the tension it will have to withstand as the ring cools to the temperature of the support ring. It may also be necessary to reinforce the joint with one or two pieces of drill rod.

I also recommend that you use a short piece of rack -- 6 to 10 teeth -- to hold the ring together while you are doing the welding. This will insure the tooth to tooth spacing remains the same across the weld joint.

For a starting point, I recommend allowing 1/2 mil (0.0005 inches) per inch of diameter for the differential between the inside of the ring gear and the outside diameter of the gear support ring. For example, with a 30-inch gear, start with the inside diameter of the ring 15 mils smaller than the holder. This diameter is easily measured by measuring the circumference of the ring and the support using a thin, flat tape and dividing the difference by π. Remem-





The declination (left) and right ascension (above) drive gears of this 12-inch reflector's mounting are made of steel rack. The gears are 24 and 30 inches diameter, respectively.

ber to take into consideration the thickness of the measuring tape. The thinner the tape, the more accurate the measurement.

For inside diameter measurements, add (2π x 60 percent of tape thickness), and for outside diameter measurements, subtract (2π x 60 percent of the tape thickness) from the measured circumference before dividing by π. For example, for a 5-mil thick tape, add 19 mils to the inside diameter and subtract 19 mils from the outside diameter to give you the net differential circumference. Then divide that number by π to obtain the differential diameter. For a 30-inch gear and using 5-mil thick tape, the differential measurement would be:

(15 π) + (2π x .60 x tape thickness)
= 48 + 38 mils = 86 mils

This is approximately 3/32 of an inch on any standard tape.

You might want to try my formula and measure a metal 5 gallon bucket to satisfy yourself before you try to make the final cuts on an expensive support ring. IMPORTANT: Make the ring gear first! Measure and calculate its inside diameter, then machine the support ring to fit it appropriately.

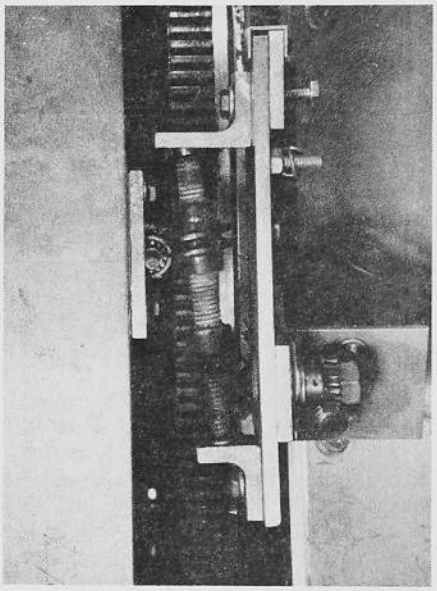
Obviously if your weld doesn't hold the first time, reduce the diameter of the support ring a few mils at a time and/or strengthen the joint until the weld holds.

The pitch diameter table gives specs for 360-tooth gears. To reduce the tooth-to-tooth runout created by forming the rack around in a circle, thus effectively increasing the tooth-to-tooth spacing along the pitch line, I would use a minimum of 360 teeth on the ring gear. On my 17.5-inch I'm currently changing from a 12-pitch 359-tooth ring gear to a 24-pitch 720-tooth to alleviate this problem. Additionally, the 24-pitch worm has six contact teeth whereas the 12-pitch only has four. On the 17.5-inch telescope I had to reduce the worm to approximately 2-1/2 teeth to alleviate the worm gear jumping on each revolution because of the runout.

The thinner the strap is, the less this effect will show up, however, because the ultimate tensile strength sets the lower limit. If the strap is too thin, it will stretch out of shape, causing a similar or even worse runout problem. The table of recommended strap thicknesses shows how much material remains from the root of the tooth to the backside of the rack and my recommendation for the strap thickness.

Practically speaking, the 24-pitch is a good option for large scopes with drive gears up to at least 5 feet in diameter. Although not necessary for a well balanced scope, the 1/4-inch steel rack can easily handle differential forces of 25 foot-pounds at the worm while revolving, and at least a hundred foot-pounds in a static position.

When choosing the combination, be sure to use the same contact angle rack and worm, i.e., make sure both are either 14.5 or 20 degrees. I



prefer the 14.5-degree because the tooth is steeper at the worm/rack contact point and is easier to keep the system from jumping teeth when you are setting up for zero backlash. Zero backlash can be accomplished quite easily by providing for a light spring load between the worm and the rack.

Last, design the worm gear mount properly. Because the lead angle on the worm is 4° 46′, the drive center line must be offset from the rack by this angle in order to provide a nice, smooth working gear system.

Any comments on this idea would be appreciated.

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Remote Control Collimation

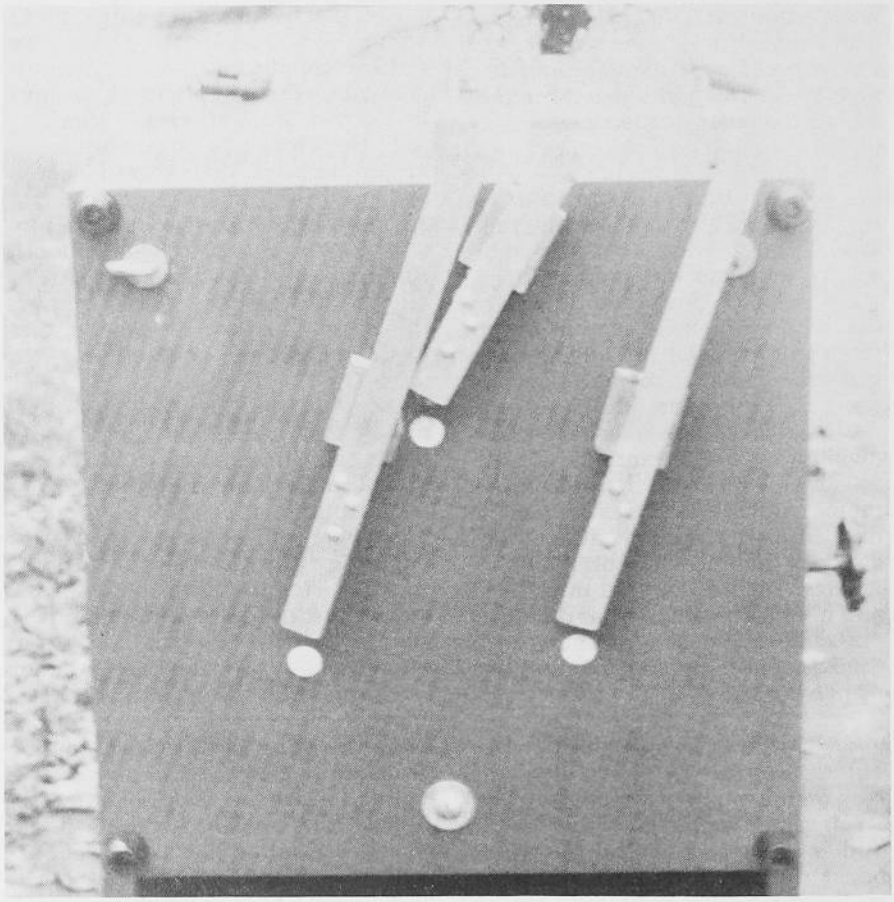
I often envied my more talented compatriots, who with a few deft tweaks of the collimating screws got perfect images, while I struggled for up to twenty minutes to get my f/4.5 optics satisfactorily aligned. As a handicapped TN, the exercise was frustrating and exhausting. After getting everything properly "set," I was often too tired to do any serious viewing.

In any case, what used to be a frustrating chore is now nothing more than two minutes of easy tweaking while viewing.

The design evolved from several considerations. First, if it didn't work out, I did not want to destroy the mechanism that Coulter had provided (being cowardly I didn't want to burn my bridges). Second, whatever mechanism I did employ, I did not want it to interfere with the opening of the "tail gate."

In addition, the adjustments had to be easily reachable while observing star images from the eyepiece, repeatable, and stable. Furthermore, the mechanism would have to be something I could build from readily available standard parts with hand tools and be cheap.

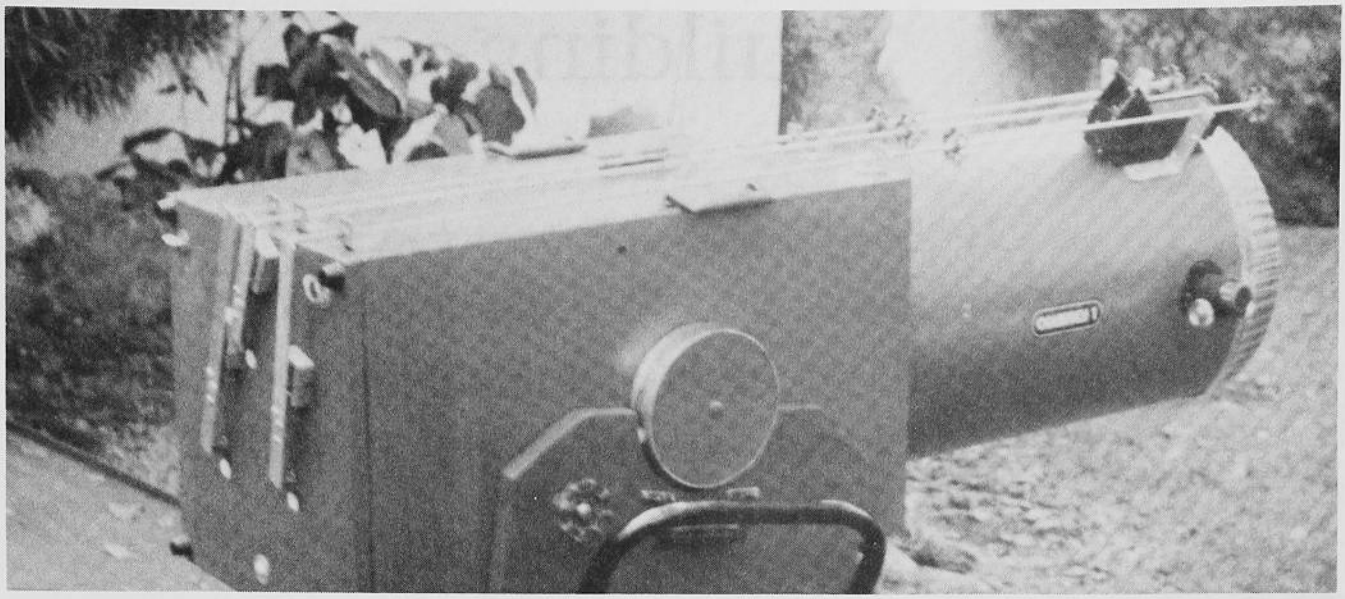
The final bill for the material was $35 and, while the workmanship is admittedly crude, the scheme works like gangbusters. I'm sure the idea can be refined by others more physically able. Perhaps this all has even been done before; however, in this cheap and simple implementation it may still interest some people. If I have inadvertently stolen the idea of someone else, my humblest apologies!



Essentially, three spring-loaded push pins that substitute for the original 1/4-20 collimation screws now support the mirror. I made the pins from large nails that slip through the original captive nuts on the tailgate and press on the mirror supports.

Three pieces of flat bar are mounted on strap hinges, placed so a 2:1 leverage is obtained to actuate these pins. This gives me the equivalent of forty threads per inch on the collimating screws. The hinges are mounted on the bottom of the tailgate on wood spacer blocks.

The lower ends of the flat bar levers press on the push pins; the upper ends press against threaded rods that run the length of the telescope tube and terminate in adjust-



At left, tailgate levers do not interfere with opening the tailgate. Above, long rods allow adjusting collimation from the front or middle of the tube. The simple techniques shown here for remote-control collimation of a Dobsonian telescope may have applications in other areas of telescope making, or in making very large portable Dobsonians more practical.

ment knobs close to the front of the tube. The brackets, made of angle iron, space these adjustment rods away from the cradle box and telescope tube. The brackets closest to the tailgate are threaded; the rest have slightly oversized holes and are not threaded.

I added a second set of adjustment knobs a few inches above the cradle box to facilitate collimating when I'm adjusting the telescope on a star near the zenith. Once a proper adjustment has been reached, three nuts can be tightened against the middle brackets to hold the rods motionless.

This system is surprisingly stable. I've found I can open and close the gate repeatedly without any need to recollimate the optics. Of course, after transporting the telescope any substantial distance, the knobs must be tweaked again for best results.

The project took me three weeks, but I have three paralyzed limbs. An able-bodied individual could do it with hand tools in perhaps fifteen hours.

Jack M. Lowenstein
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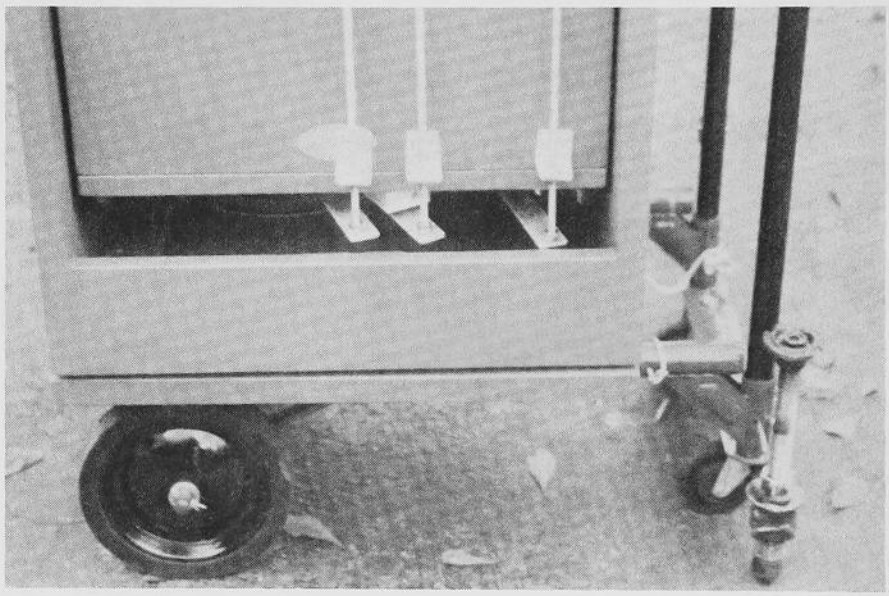
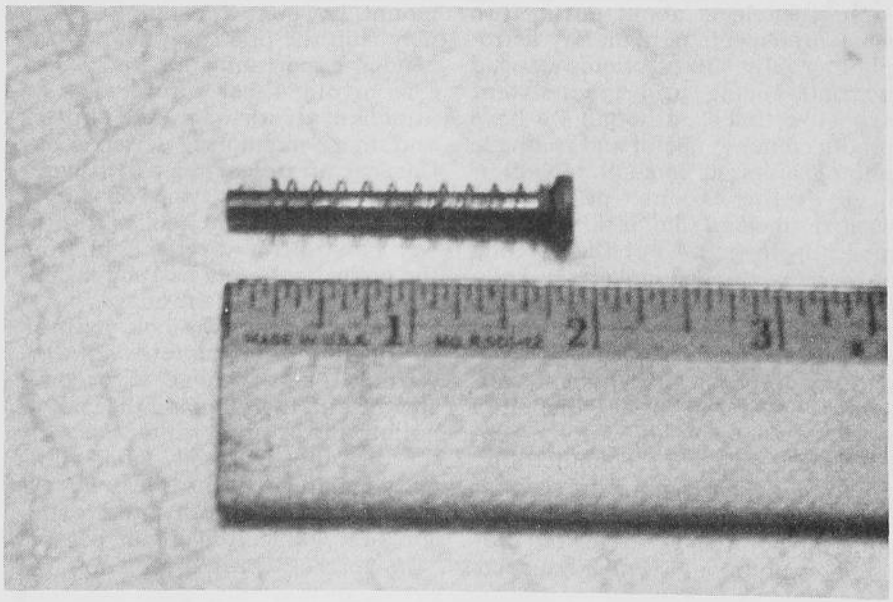
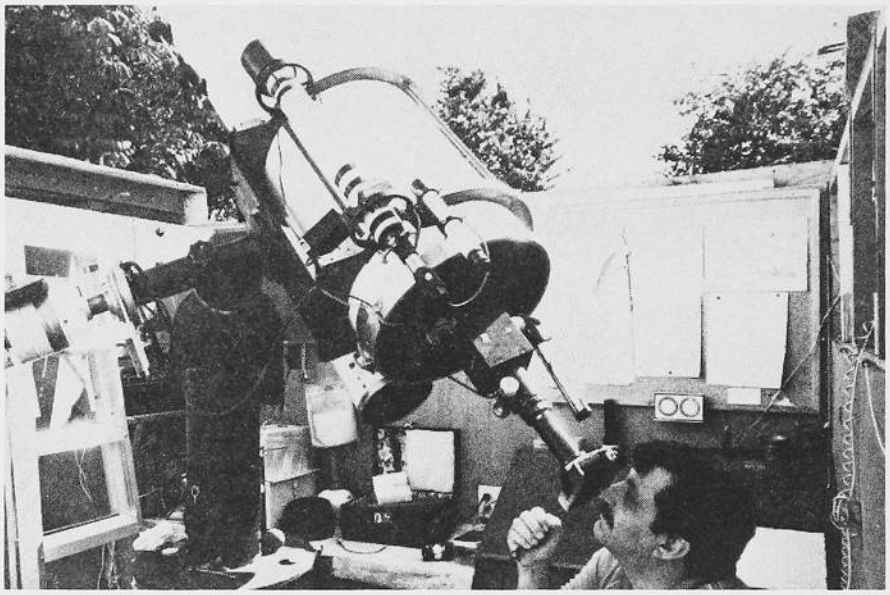
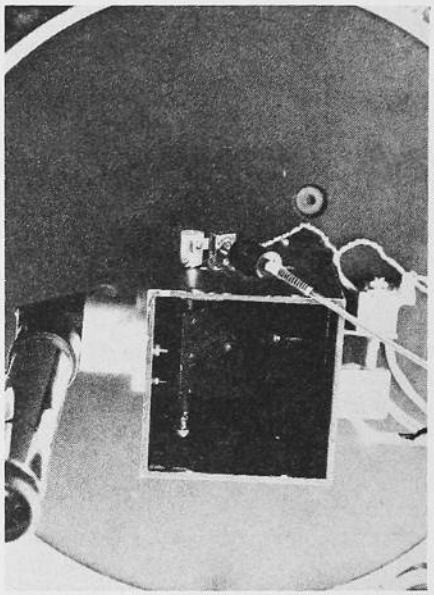




Building a Precise Shutter for Planetary Photography





This article is about curing two wasteful aspects of planetary astrophotography: fuzzy photos caused by bad seeing and inconsistent exposure times. Although we have produced many useful and aesthetic photographs, it has all too often been at the expense of a lot of wasted time and film. It doesn't take a genius to figure out that getting only one or two good images out of a roll of thirty-six is a poor way to go.

The ability to monitor a planet right up to the instant before exposure is probably the greatest contributing factor in the production of quality planetary photographs. Seeing conditions vary considerably, sometimes from second to second, during the course of a night, and we must take our best shot for the prevailing conditions. Even with a solid mount, however, camera mirror slap may ruin the photograph when the window opportunity arises.

To avoid these problems, we attached an air-operated shutter and image-monitoring device to our Cassegrain telescope, with very good results. The device consists of a hinged mirror that acts as a shutter. This mirror diverts light from the optical path to a low-power ocular used to monitor the image.

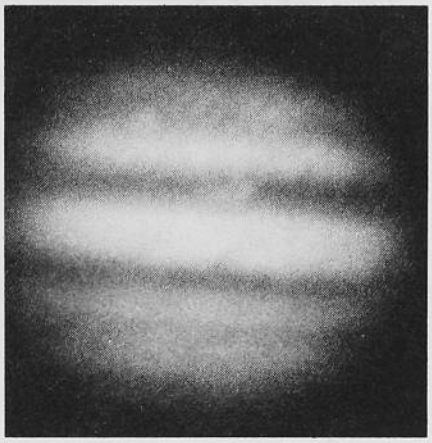
For many years we took pictures by opening the camera shutter, waiting for the image to become steady, and then flipping the combination mirror and shutter up with the air bulb. However, I had difficulty making exposures less than a second and found consistent exposures very difficult to obtain.

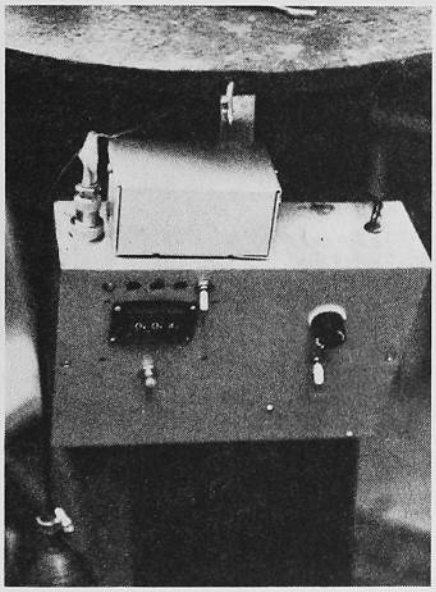
To correct these problems, we devised an electronic shutter-closing control. Air pressure to open the shutter is supplied by the hand-operated air bulb (1) to the shutter actuator piston (5) via tubing (2) and routed through a "T" to the 12-volt solenoid-operated air valve (3). As air is driven into the piston, a plunger pushes against the shutter cam, forcing air out of the way and actuating the timer switch S1. This enables the image to reach the film plane.

At the same moment a countdown timer is started. When the predetermined time runs out, the solenoid is supplied with power to open the valve and release pressure from the piston, which allows the shutter to close. A check valve (4) allows air to quickly refill the bulb.

After the shutter has closed, the

Jeff Beish does his planetary work with a 32cm Cassegrain telescope. Photo at left shows his camera's shutter with the camera body and projection tubes removed. The solenoid and check value are visible to the right of the shutter box. The timer control box (below) and 12-volt power supply allow precise exposure-time control. Right, Jupiter and Saturn by Beish; Jupiter 6-6-85, 1.5s @ f/85, Saturn 7-16-85, 4s @ f/122. Both planets shot on Kodak 2415 .





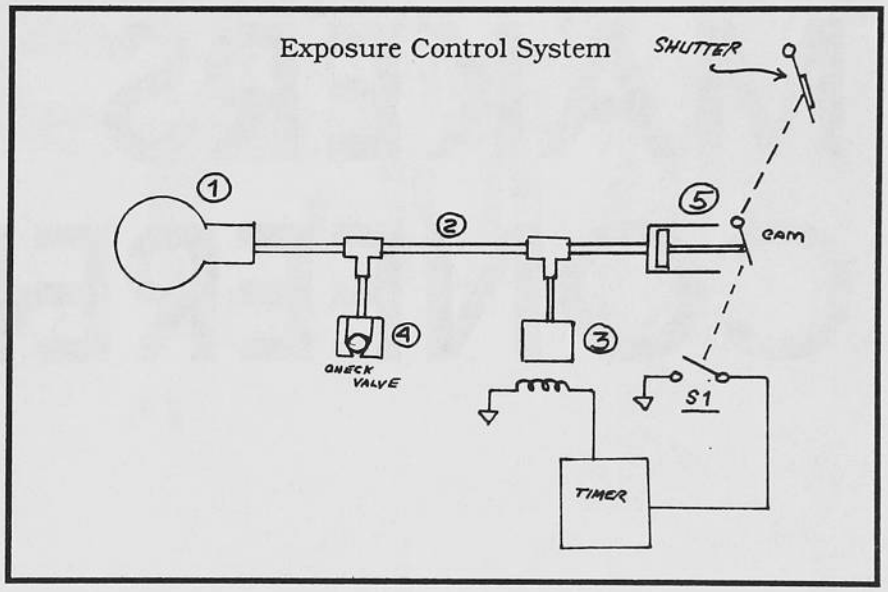


image may again be monitored, and a second exposure may be made on the same film frame.

The shutter and monitoring device presented has been a positive force in the right direction to make astronomy more enjoyable to us. Producing quality planetary photographs and at the same time cutting down on the cost and wasted time has enabled the authors to devote more time to observing.

Don Parker designed the original seeing monitor for use with his Newtonian telescope. Beish modified the device for electronic control and for use with a 32cm f/30 Cassegrain telescope.

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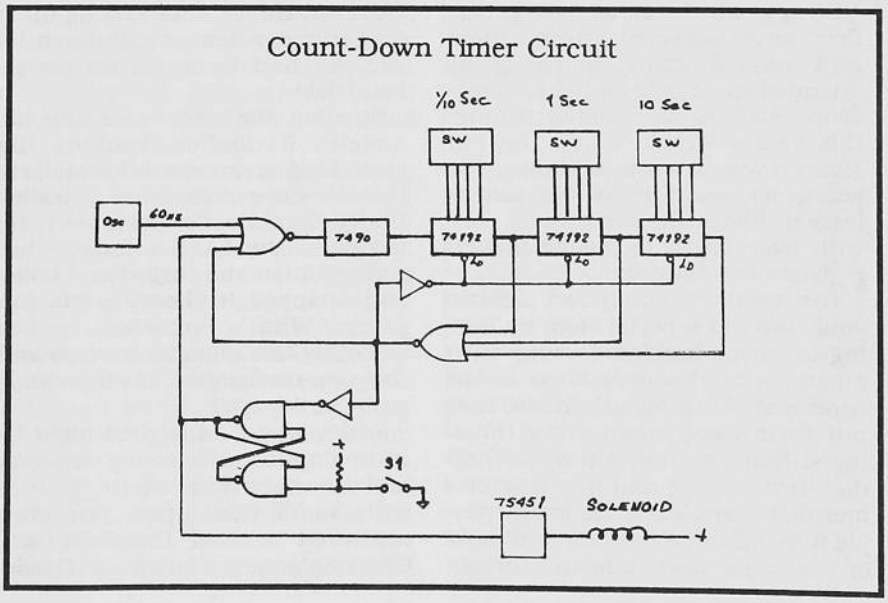


The 1988 RIVERSIDE TELESCOPE MAKERS CONFERENCE

Strong winds blew, gritty dust flew, snow squalled around them, and near-freezing morning air attended the hardy and cheery telescope makers who lasted through this year's RTMC. While the Full Moon drove down attendance, this year was nonetheless the second largest Riverside conference ever, with over 1,800 telescope makers registered on Saturday.

The weather conspired against your intrepid reporter, too, by forcing telescope builders to wrap their creations in plastic or tarps as the wind rose Saturday afternoon, then put them away when snow threatened that evening. Although Sunday turned clear and bright after a morning of snow flurries, many people were off the mountain and most of telescope were safe in storage-

However, things were looking up by dinnertime, when several dozen telescopes had been set up on the main field.

Stealing the show was the Los Angeles 31-incher. Looking like some kind of knocked-down oil rig, the telescope arrived on a trailer. Under Tom Dorff's command, the troops of the LAAS telescope brigade grunted and tugged and bolted and snapped its heavy parts into place. What's amazing is how smoothly this monster moves—with the axes unclamped, it will actually swing in the wind.

Friday was a fairly good night for testing optics—the seeing was good and the lines were short. I stuck with small telescopes, refractors scattered around the field, and Christen's new Houghton Cassegrain. The 9.5-inch prototype he had appeared to give very fine images. Dick Buchroeder and I both had a chance to look through a 5-inch f/8 Starfire, and agreed that it was an excellent lens (Buchroeder even said so to Christen). The beautifully restored Goto 6-inch achromat was, by comparison, a terrible dissappointment, with purple-hued crater rims and yellow peaks catching the first rays of sunlight. I guess I've gotten spoiled.

I later tested Jim Heaton's 7.5-inch f/17 doublet and his folded 6-inch f/15 super-planetary triplet. I must admit to prefering the colorless images of the triplet, but the doublet was very good. Heaton explained that he's been working on the 7.5-inch for several years now. "I started work on this lens when I

By late Friday afternoon, lots of people had arrived, the vendors were out in force, and it looked like a magnificent weekend was on the way.

didn't know what I was doing," he explained, "and I've just kept working on it. It's good enough now I'm not in any hurry to do more, but I will do more next time I can borrow John Pons' 12-inch quartz flat."

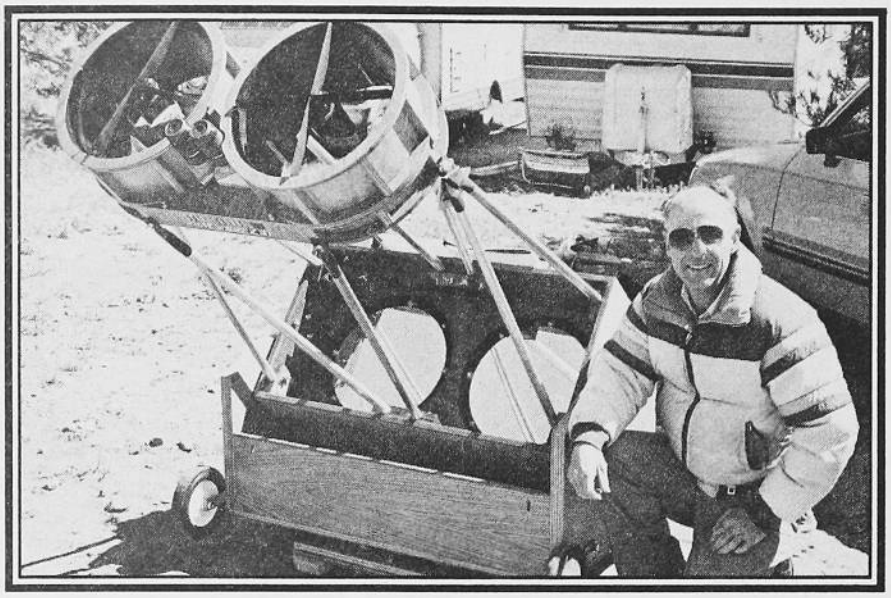
The LAAS 31-inch reflector had a long line, so I kept coming back to it hoping to find the line had gotten shorter, but that never came to pass. Around midnight, the line suddenly disappeared—I later found out that the scope had been shut down because of a dead battery and exhausted operators. My own batteries were pretty close to dead, so I called it a night.

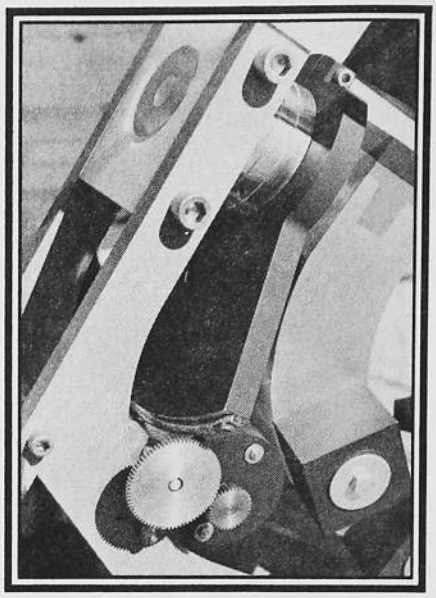
Saturday was my big day for telescopes. All morning and into the afternoon I worked my way from scope to scope. By 2 p.m. it was becoming clear that the increasingly gusty winds and blowing grit would force a lot of owners to either cover their instruments or let them fill with sand. Because of this, I didn't get to see all the telescopes that won merit awards.

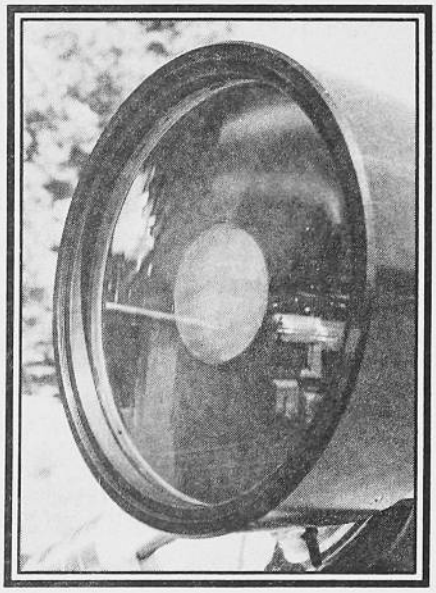
Saturday evening brought the big twentieth anniversary celebration, with a glittered-studded dinner honoring the nineteen- and twenty-year veterans of the RTMC. I watched the ceremonies on closed-circuit television, as Bob Schalck reviewed the years of Riverside. "In 1979 we had 746 people—enough to qualify us as the biggest star party in the world," he proclaimed, "and in 1980 we got snowed on." 1981 brought the invasion of the wooden telescopes, and Riverside broke the 1,000 barrier.

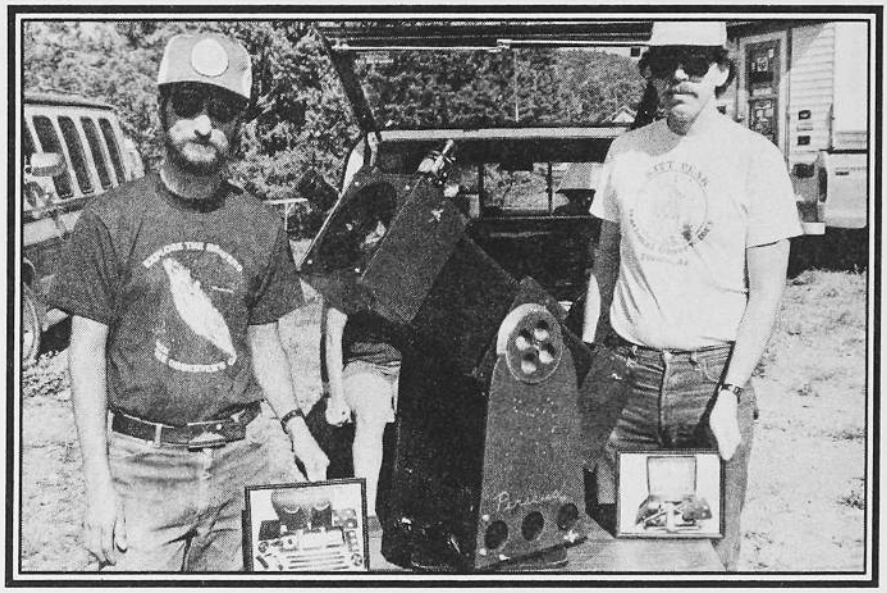
Schalck's narrative brought back a lot of memories—years of taking photos and taking notes, analysing and writing about what I'd seen, scribbling about the newest and neatest ideas I saw presented. Riverside's twentieth year was not a year of innovation, but a year of refining ideas, testing variations, building bigger telescopes, and pushing the design boundaries back just a little farther. And—despite the weather—a lot of people were trying.

On Saturday night very few people observed. With winds gusting to 50 miles per hour and temperatures in









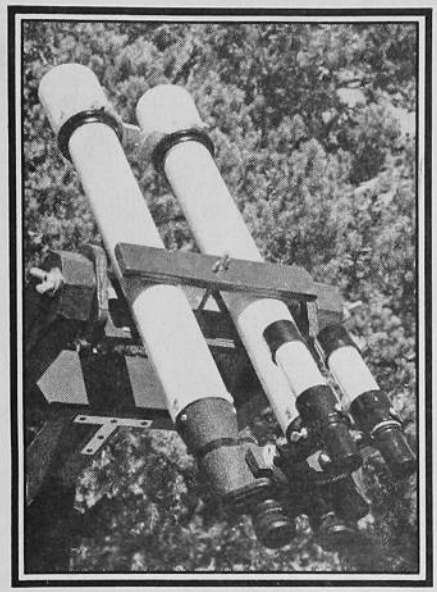
the 40s, it was a bit too rough. I borrowed Pete Manly's image intensifier—and shot pictures of blowing clouds of dust on the telescope field. Sunday morning brought snow squalls to the breakfast line, and chilly winds. It was a fine day for talking to people (indoors) and listening to the papers presented n the mess hall.

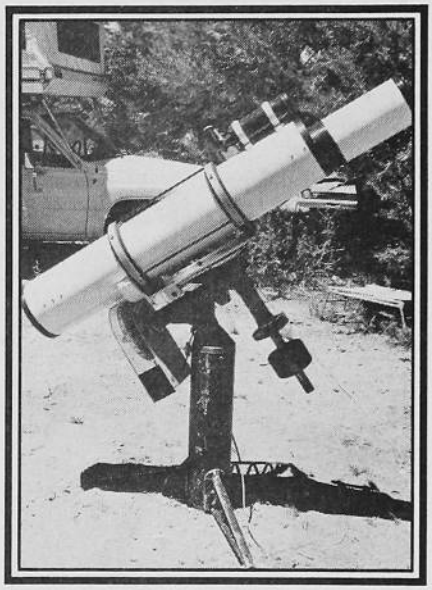
The Merit Awards (listed on page 37) and Bozo awards were presented Sunday evening, to a small but lively audience. "I'm happy to say we had a hard time," said Randy Wilcox, chair of the Merit Awards committee, "and I'm happy to see more people trying to build a telescope and even push glass."

The committee, after considerable debate, ruled out giving awards to incomplete telescopes. "Get the bugs out," said Wilcox, "get it tuned and balanced and working right, then bring it back next year."

The twentieth Riverside was also a year when the line between commercial and the hobby became almost hopelessly blurred. A number of enterprises tucked their sales literature out of sight when the awards committee appeared, and put it out after they left, but the committee saw through their ruse. "When you go commercail," said Wilsox, "you get your reward in monetary return. We don't want you to use the Merit Awards to promote your commercial product."

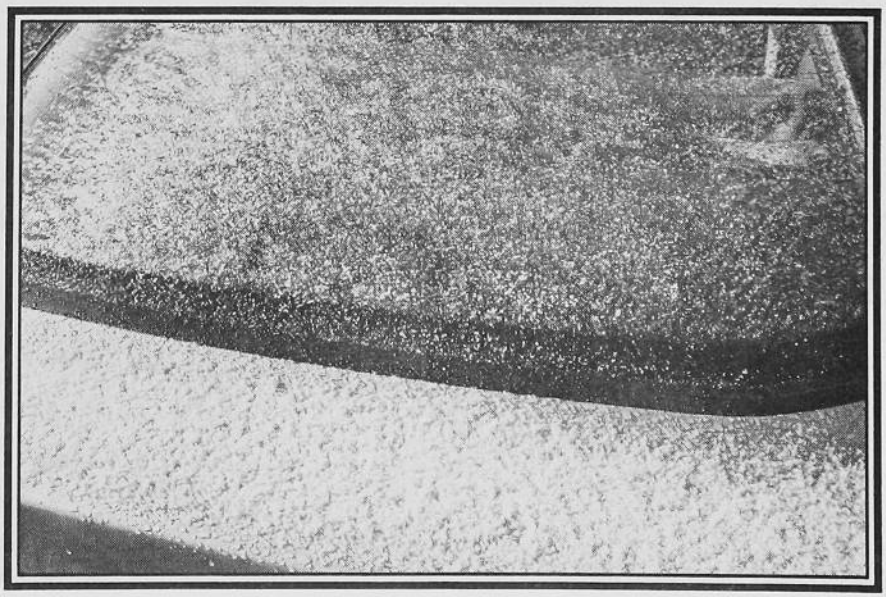
Overall, 1988 was a good year for RTMC. Despite the weather, the Full Moon, and lowered attendance, more people registered telescopes than last year.

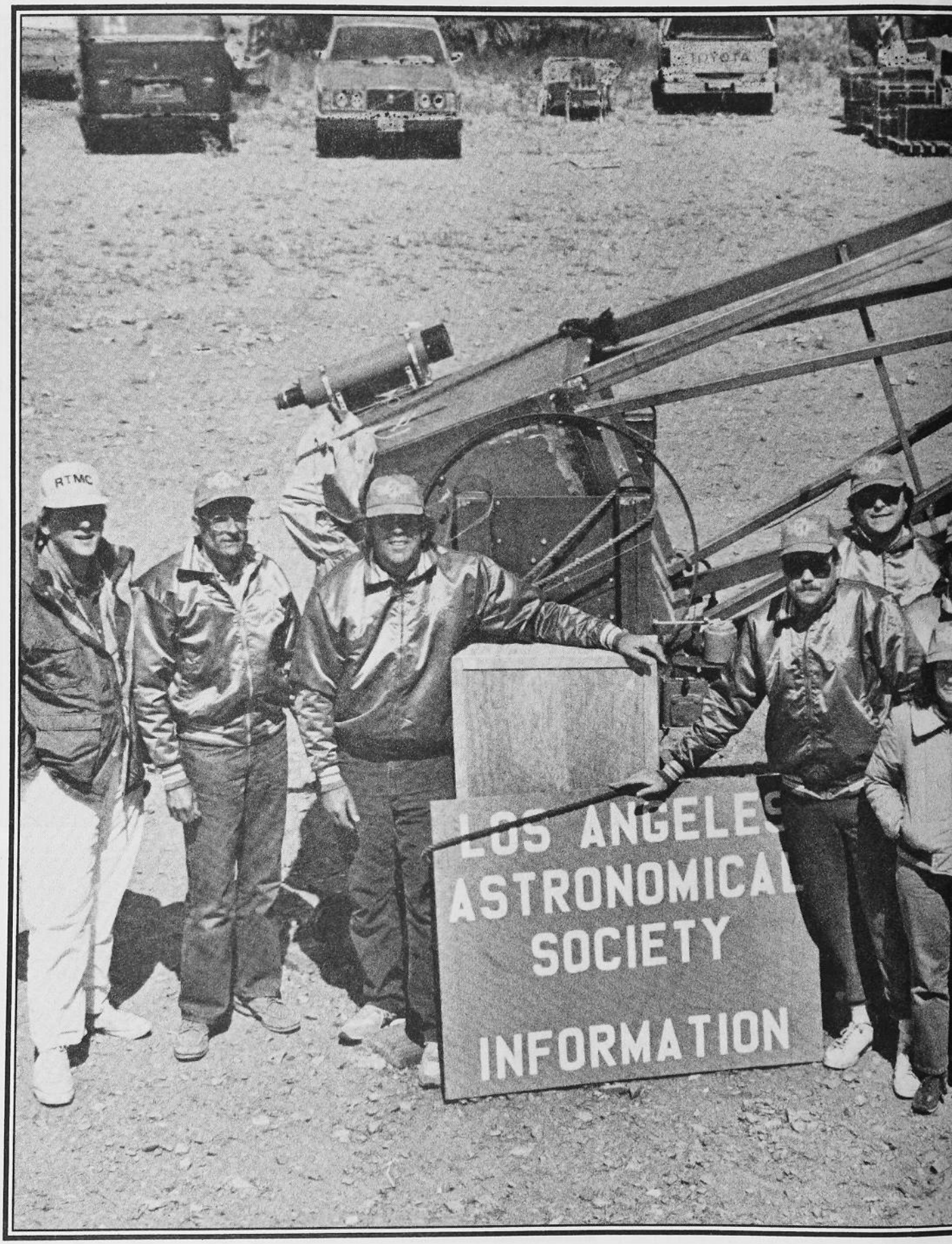




Many Telescopes and Many Ideas

Left to right, top to bottom: Robert Suding and his 14-inch binocular; the bent-bolt drive of Keith Lawson's 5-inch f/7 Newtonian; two-cheap-telescopes plus a binocular by Dave Trott; David Levy's fishing-reel controlled comet search 6-inch reflector; the corrector of Roland Christen's 9.5-inch Houghton Cass; an 8-inch collapsible telescope by Chris Schur; a rhomboid prism for checking binoculars, in the hand of Gordon Rayner; Rick Shaffer's foldable tripod; Jim Heaton's 6-inch folded refractor; and Sean Scott's 12.5-inch f/6 horseshoe mount.

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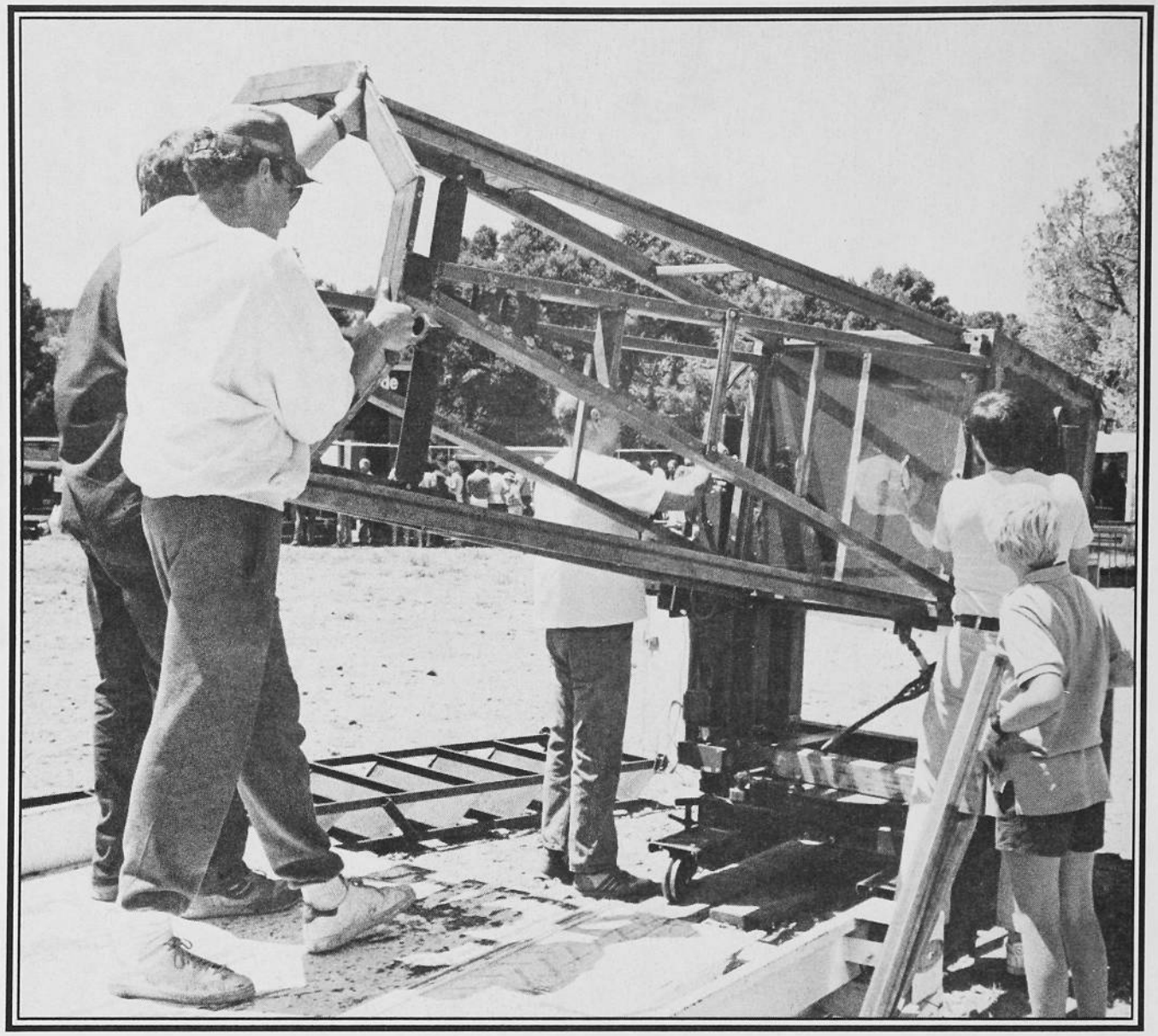
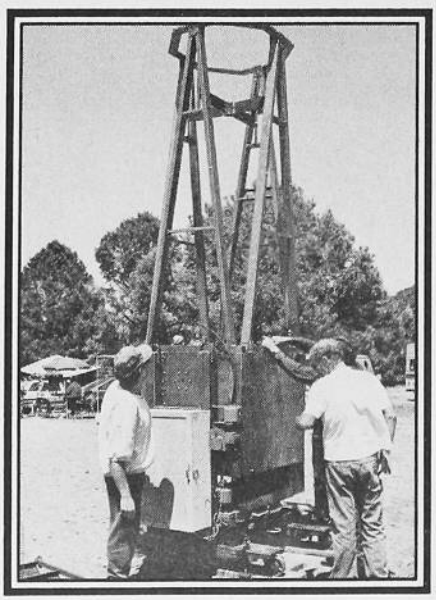
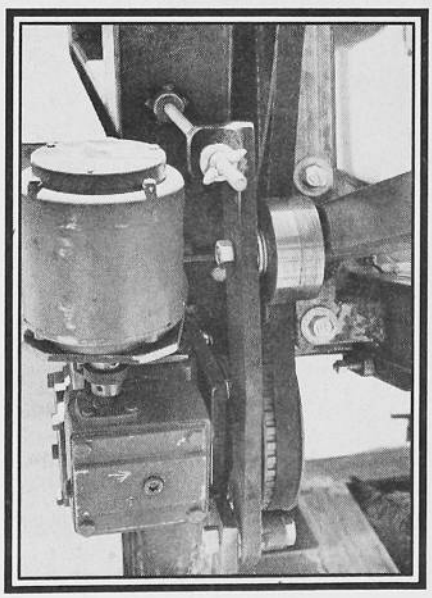
INFORMATION







Big Optics on a Massive Mount

The Los Angeles Astronomical Society, with speed that is characterisic neither of club projects nor of most large-telescope projects, brought their new large telescope on line this year, only one year after starting the job.

With stepper motors and an onboard computer, the club hopes to make the alt-azimuth telescope track the sky, and, with the aid of an object database stored in the computer, find celestial objects.

Mechanically, the telescope is a welded steel structure. Club members fabricated the huge azimuth

bearing by turning grooves in two thick steel plates, then pouring in nearly a thousand ball bearings. In altitude, the telescope rides on $150 8-inch bearings made by the Paxton-Mitchell company of Omaha.

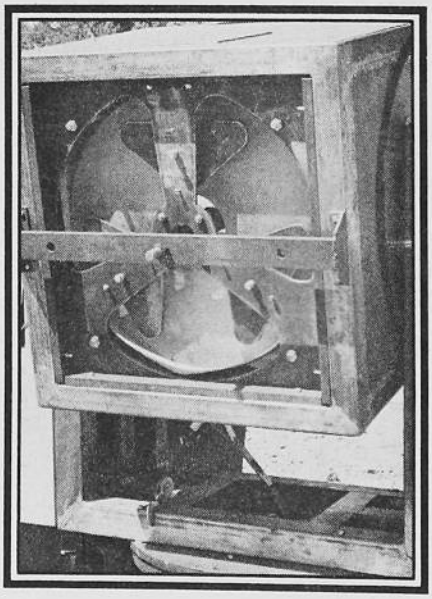
Driven in both axes by 200 step Slo-Syn stepper motors reduced through 900:1 gearboxes, the instrument will be under full computer control. Motion is transmitted to the telescope via big timing belts. An XT clone control computer will update the azimuth drive rate 14 times per second, and the altitude drive rate 4 times per second, and command a dedicated stepper-motor control board to drive at that rate.

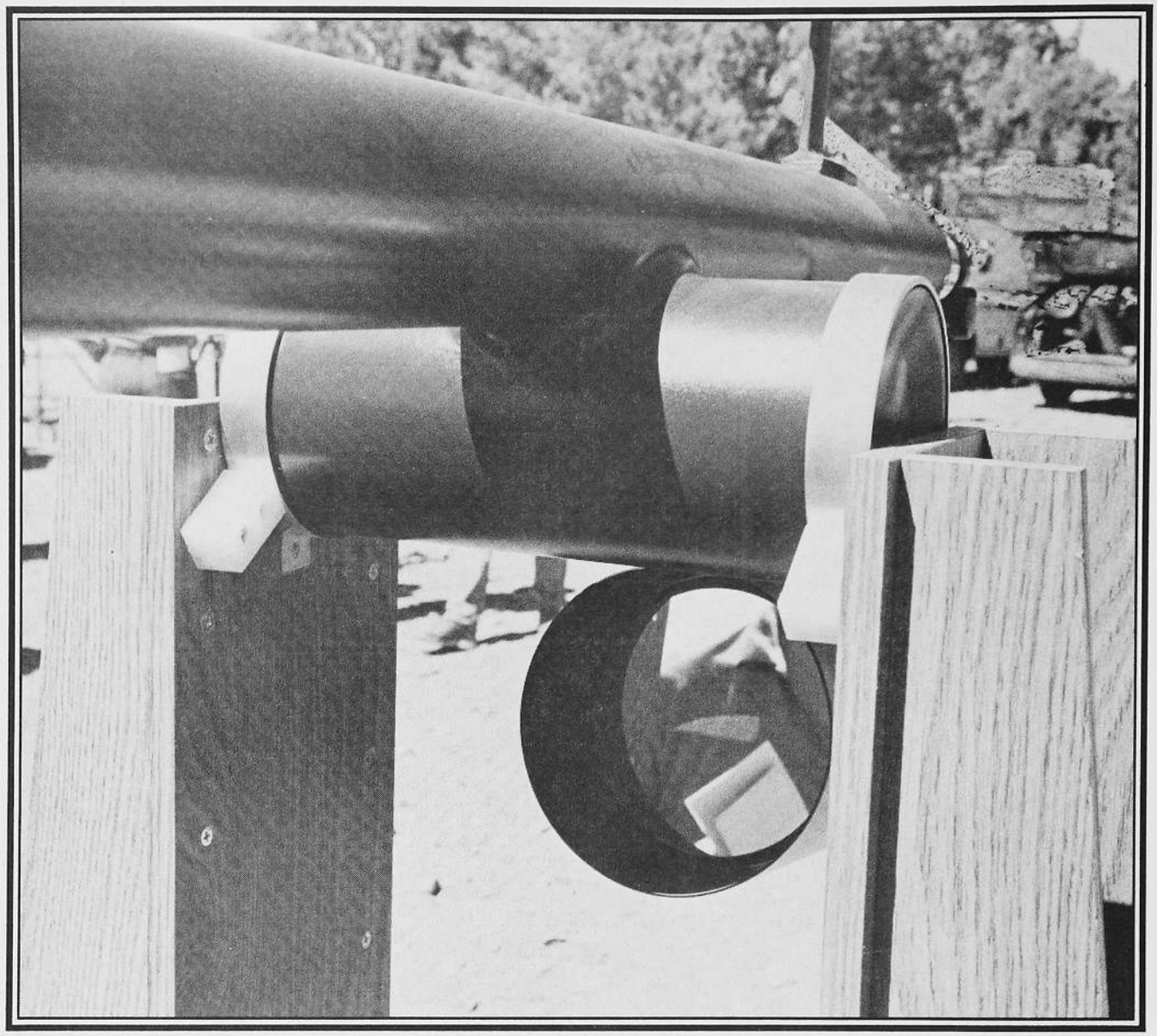
Although the software is complete and has been tested, it has not yet been used with the telescope. For photography, the computer will also command the rotation of the plateholder.

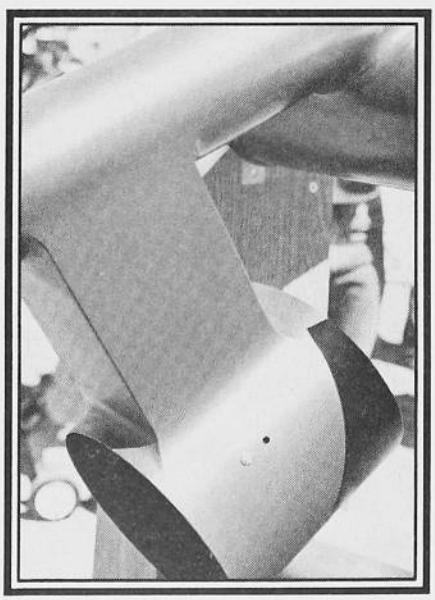
Because he helped the Society obtain the 31-inch f/4.6 primary mirror from an anonymous donor, the telescope has been dubbed "Clyde-O-Scope," after Clyde Tombaugh. The telescope can be used as a standard Newtonian, as a folded Newtonian with a 10-inch flat made in the LAAS optical shop, or with one of two Cassegrain secondaries, an f/12 and an f/20.

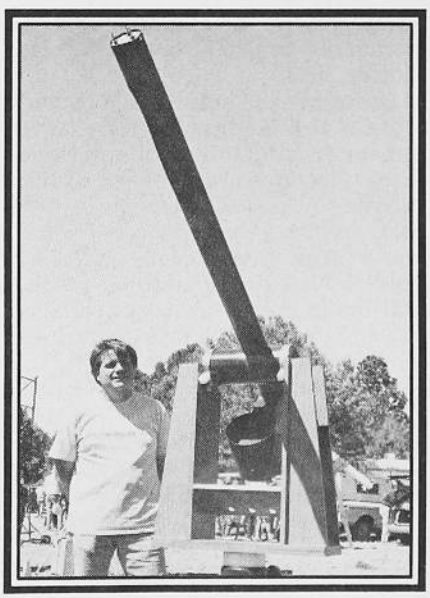
At least forty members of the Society have worked on the telescope, at every task from making secondary mirrors to sewing the upper-end light shield to welding the massive parts for the mounting.

When the telescope is completed, it will be painted LAAS blue.









Unobstructed "Schief" Optics...

According to Kevin Medlock, Jim Hendrick's 6-inch f/26 Schiefspiegler is only the fourth such instrument ever shown at RTMC.

"Making the optical system was the fun part," said Hendricks. A 6-inch Schief does not require a lens to correct astigmatism.

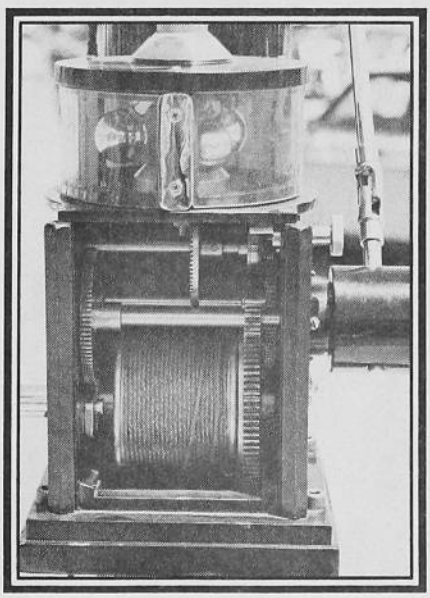
The all-steel telescope tube was built around a 3.5-inch truck tail pipe, with 7-inch and 5-inch tubes welded to it for the primary mirror and altitude shafts, respectively. Hendricks used Bondo auto-body filler so the tube "looks like one-piece construction."

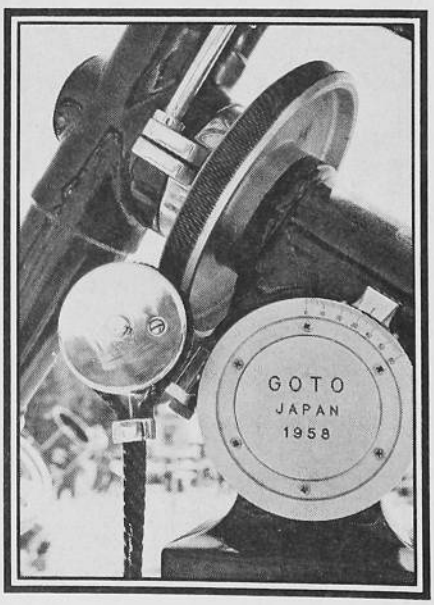
...and a Refractor Restored to Glory

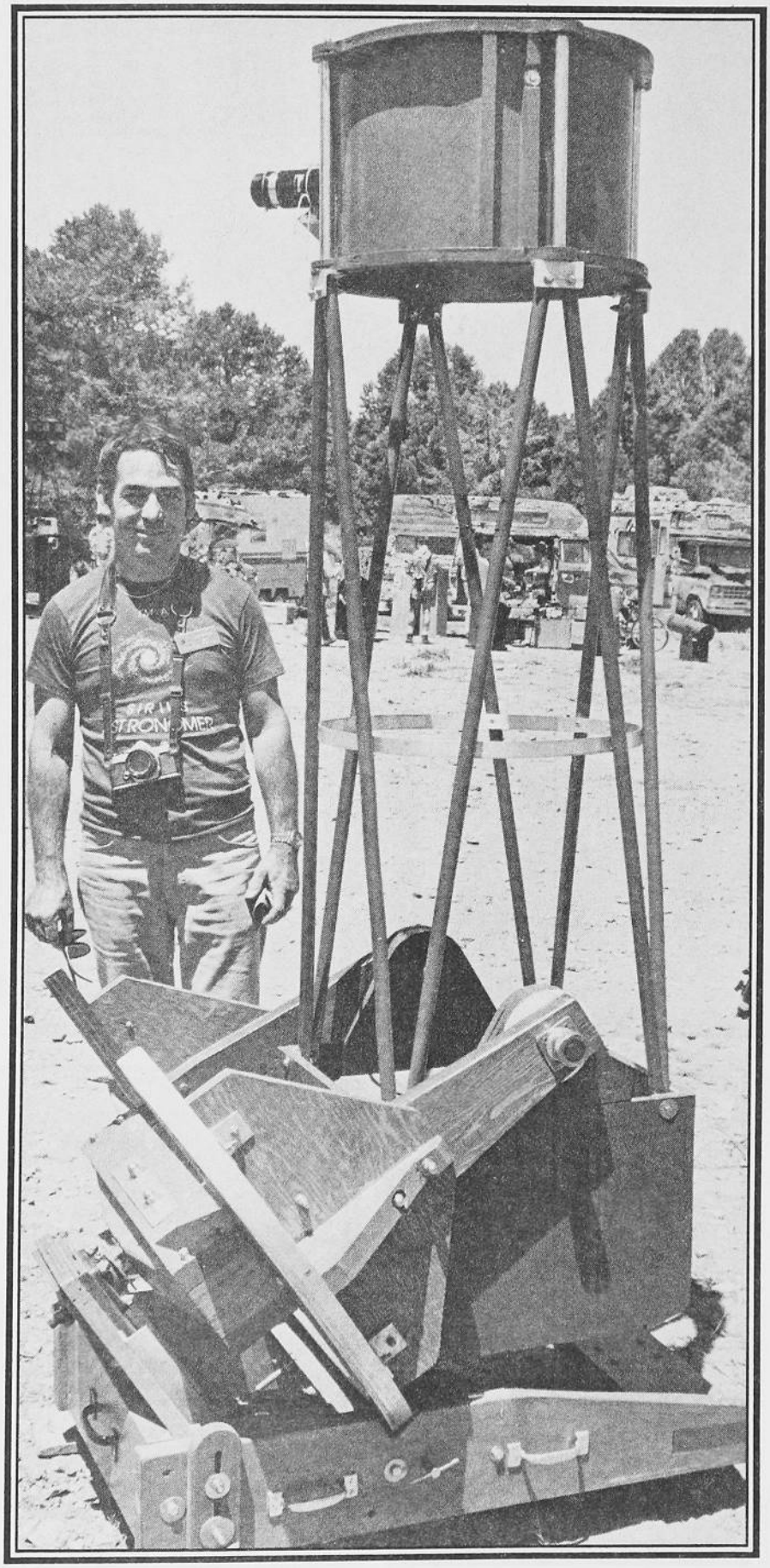
Rod Wheeler displayed a 6-inch Goto achromatic refractor built in 1958 that he purchased and restored. "It was painted battleship gray," said Wheeler, "but I really wanted the classic white, black, and chrome look of a Unitron."

The mount was completely disassembled, cleaned, missing parts such as counterweights machined, chrome-plated, and then lovingly reassembled.

Note the weight drive, cord-operated RA slow-motion, and elaborate mechanism from middle knob near eyepiece to clamp on RA axis.







Scrounged Parts Make Solid Mount

"I designed the horseshoe to be 36 inches in diameter because that was the size of the precut circles they sell at the hardware store, for tables," said Doug Ostroski. Using materials scavenged from dumpsters, and bits and pieces from salvage years and junk stores, Ostroski constructed a highly functional and solid horseshoe mounting.

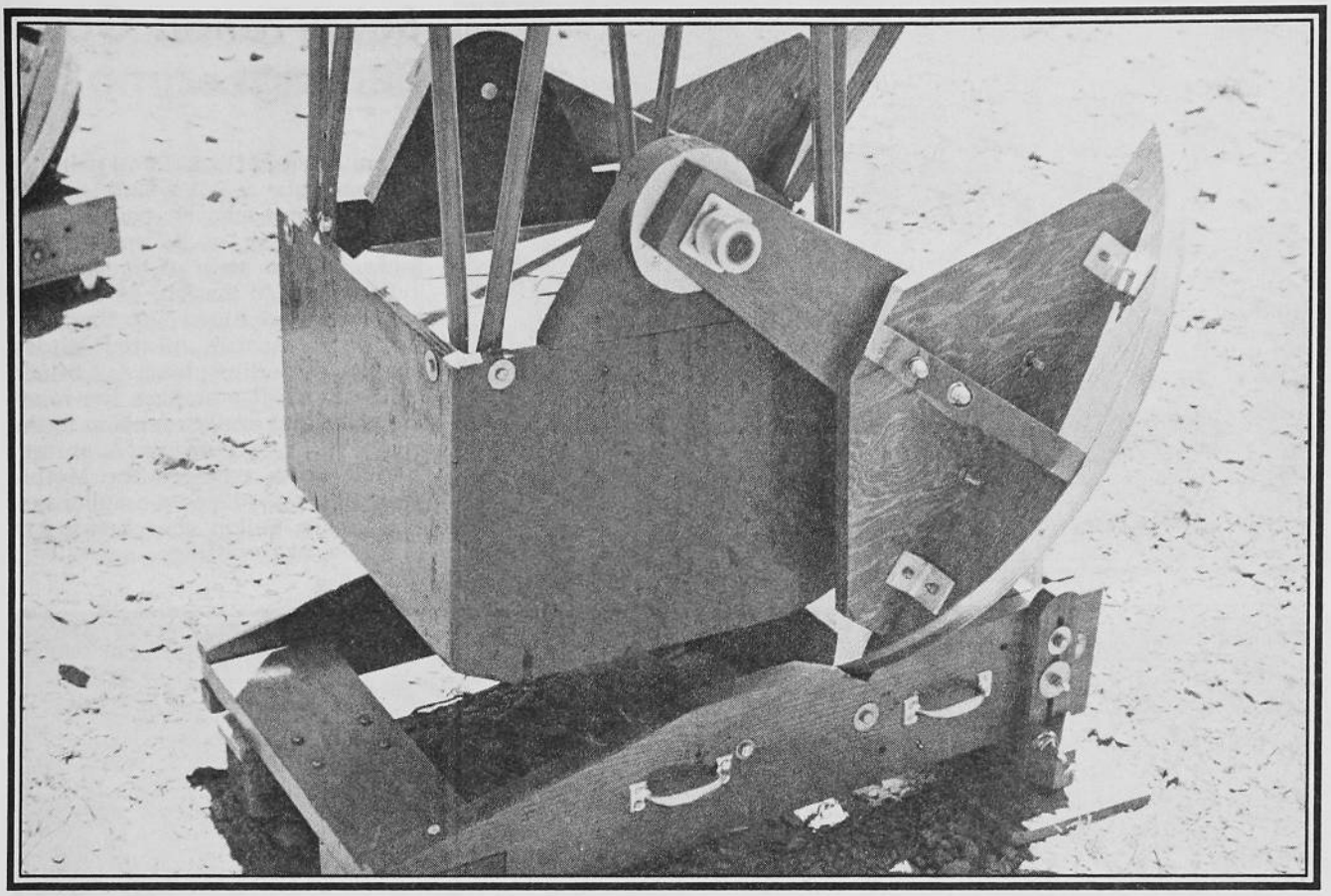
"The rods in the tube came are handles for pool sweepers," said Ostroski, "they're dented just a bit so I paid a dollar apiece for them." The beautiful declination clamps on Ostroski's mounting once held down benches on a ship; he obtained them cheap from the Navy yard. His total cash outlay was $68.

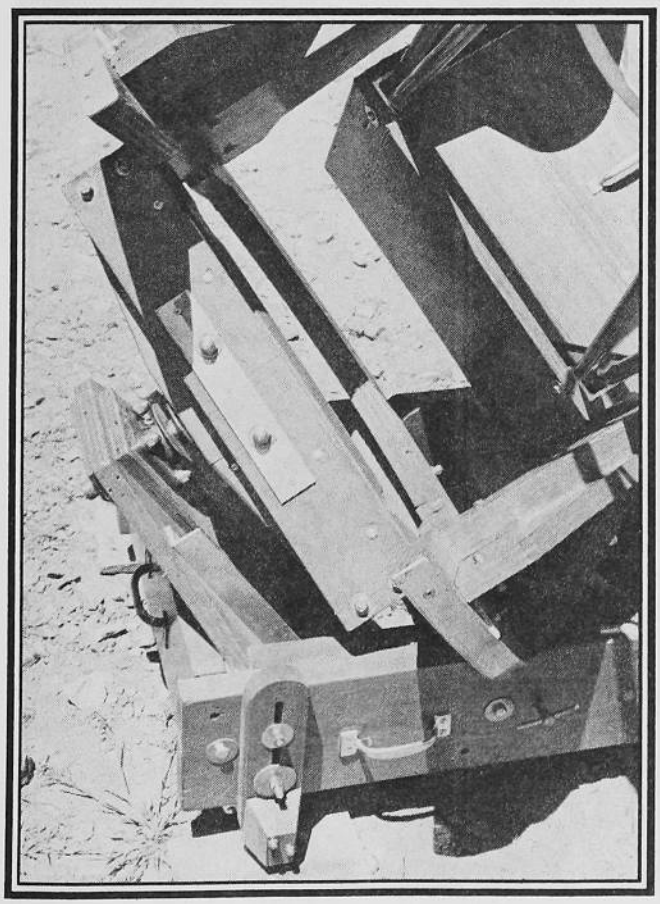
1988 was the year of the horseshoe mounting at Riverside, and Ostroski's was only one of several equatorial horseshoe mounts on display. Horseshoe designs are characterized by a large opening in the upper RA bearing allowing the telescope room to swing through the bearing. Both the Palomar 5-meter and the Kitt Peak 4-meter have horseshoe mounts.

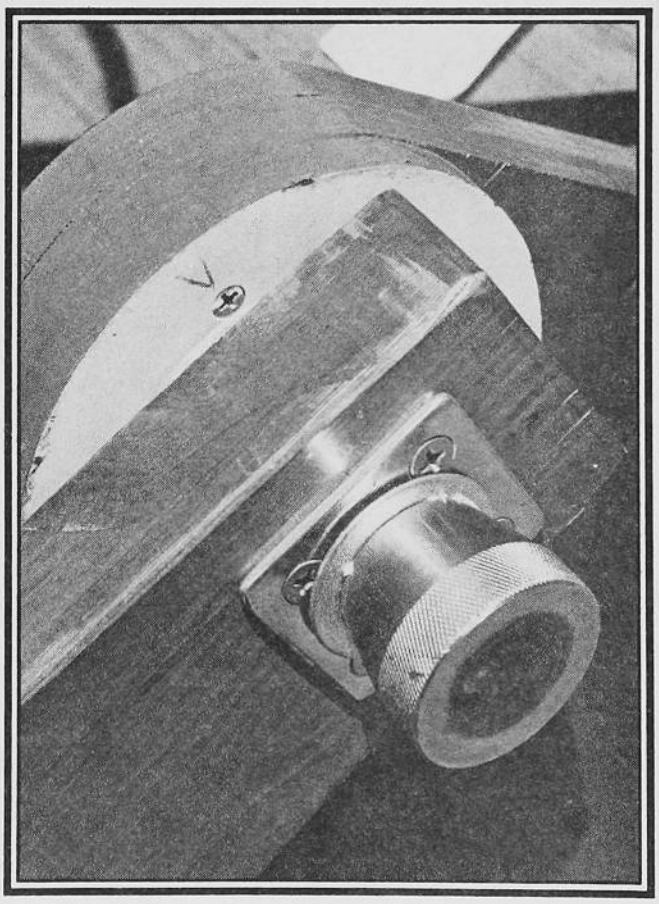
These mounts offer distinct advantages over other designs. Unlike fork designs, they tend not to suffer from flexure. Unlike German designs, they cross the meridian without hanging up on a pier. Unlike yoke designs, they're compact and low. They offer a convenient large-diameter roller-type RA drive disk, and are usually amenable to having wheels added to the bottom for easy roll-out style observing.

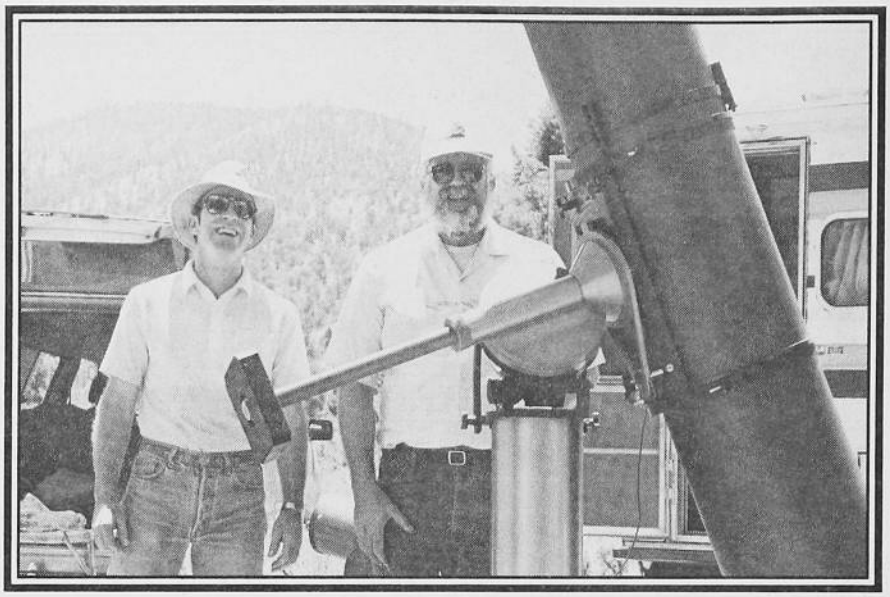
Ostroski's design, which is something of a cross between the Porter split-ring mount (see Gary Walker's design in *TM#31*, page 32) and a fork mount with a large RA bearing not cut into a horseshoe, allowed him to use a smaller bearing than a pure split-ring might have called for. "It had to fit a 36-inch disk," said Ostroski. With its short cantilever and heavily braced fork arms, the mount appeared to work very well. The mount does not have a drive; Ostroski plans to add one.

"It breaks down into three big pieces," said Ostroski, "I call 'em three easy pieces." Set up time is roughly 60 seconds; tear down takes about 90 seconds. The telescope parts fit comfortably in the back of a pickup truck.



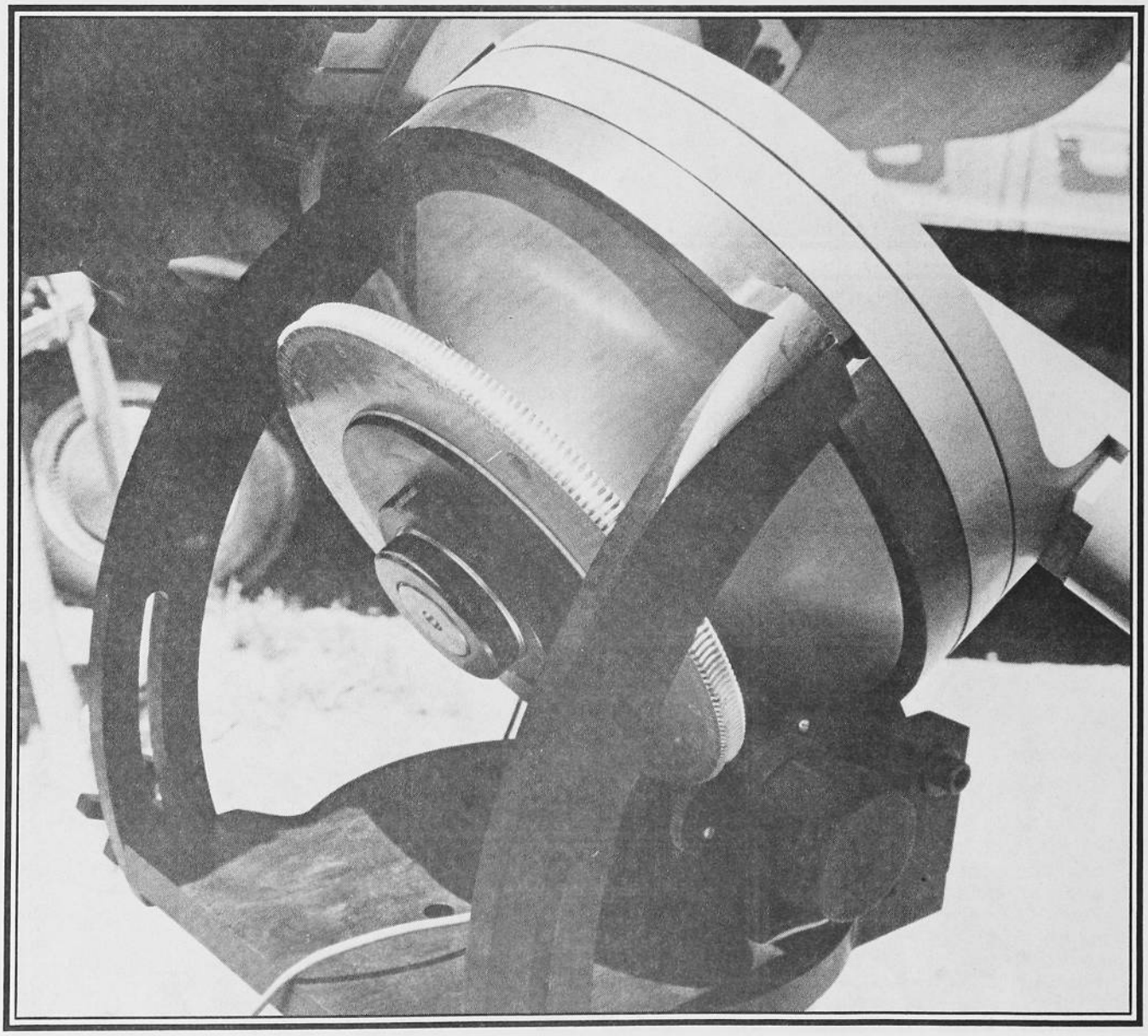






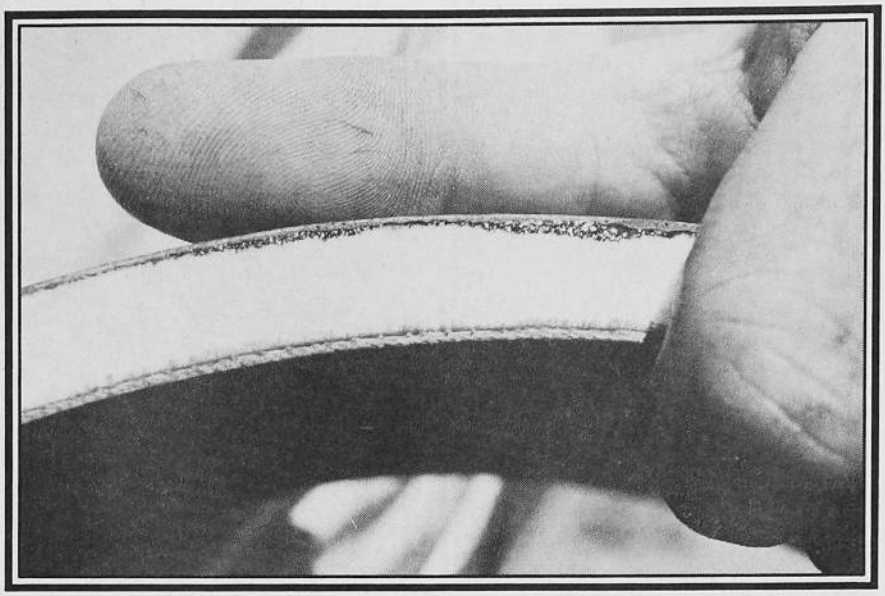
Solid Teflon Cone Bearings...

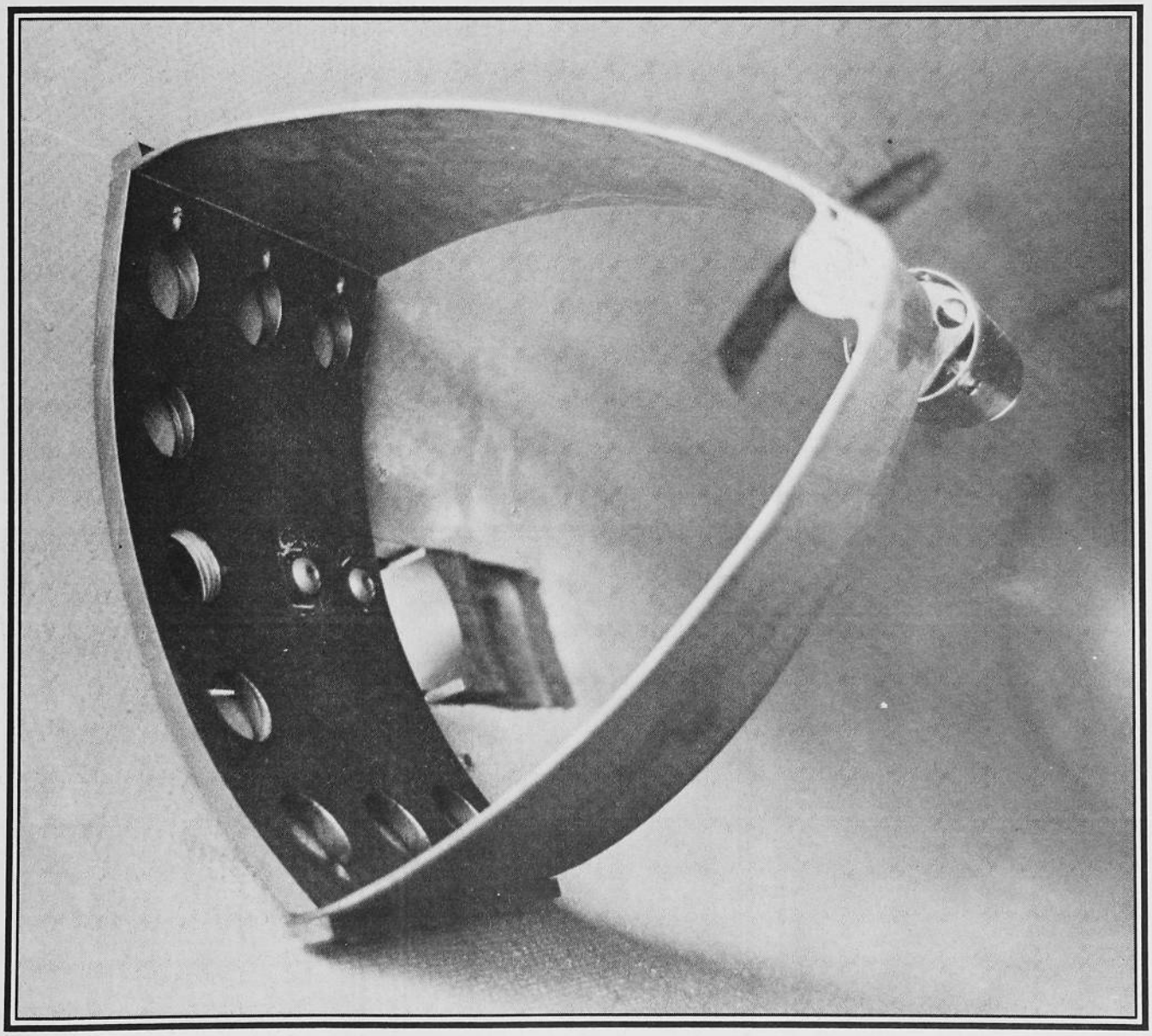
Tom Fox and David Pitou mounted the long tube of Fox's 12.5-inch f/8 reflector on a massive cone bearing that uses Teflon on its working surfaces. A thin strip of back-etched Teflon glued to the face of the shallow cones machined into the inch-thick aluminum plates slides against the other plate. A 1.5-inch diameter shaft stabilizes the rotating plate and applies tension to the northern cone bearing. A spring-loaded worm engages the Mathis gear. Pitou displayed a smaller version of the Teflon cone bearing at Riverside two years ago.

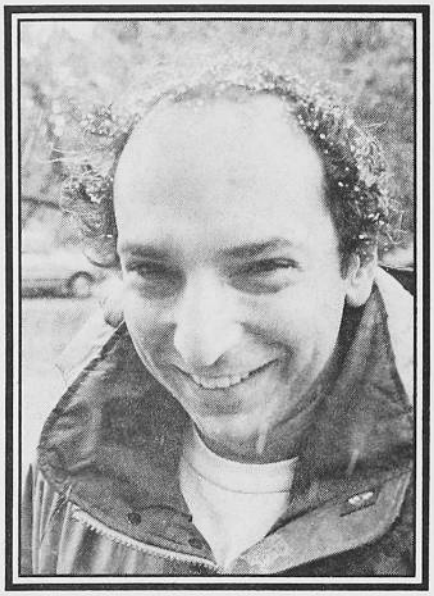


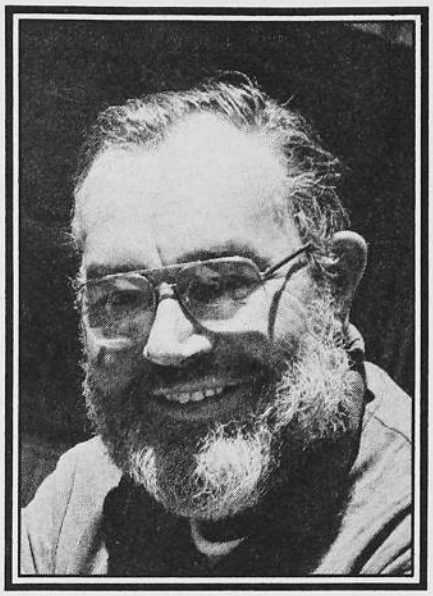
...and a Foam-Composite Tube

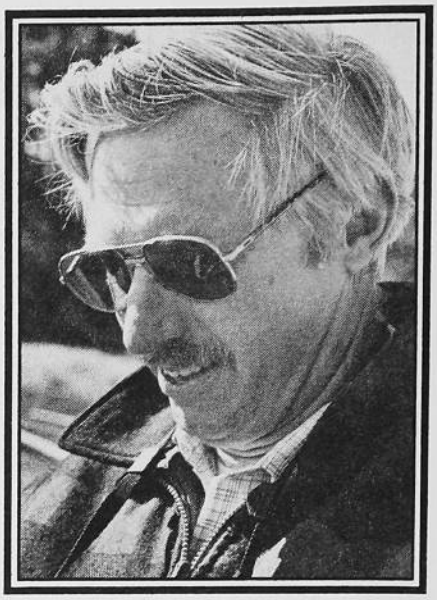
Fox contructed this telescope's strong, light-weight tube from aircraft materials. "The tube is 9-1/2 feet long and weighs only 30 pounds," said Fox, "it's epoxy carbon fiber over a foam core—the same stucture used in the Varieze ultralight." The tube splits in two sections. To show its strength, Fox sat on a 6-inch length of 15.5-inch o.d. tube; it creaked but did not crush or collapse. Inside this telescope optimized for viewing Mars this fall, an "anti-diffraction" spider moves laterally when Fox focuses the low-profile eyepiece holder.

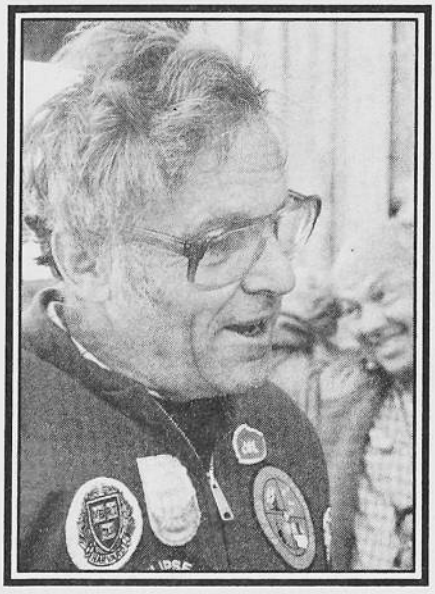






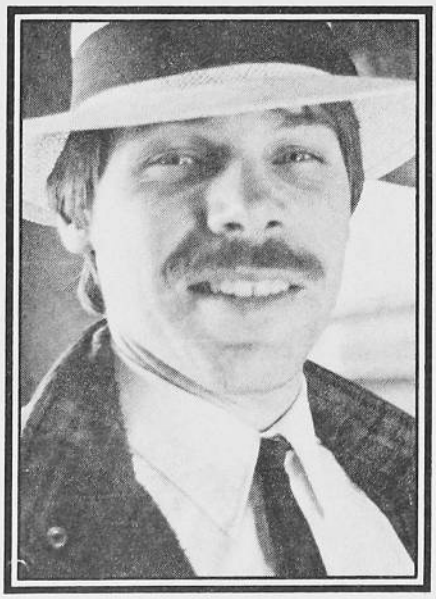


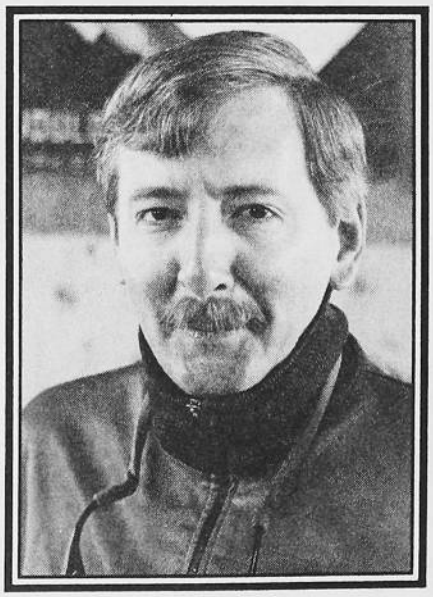


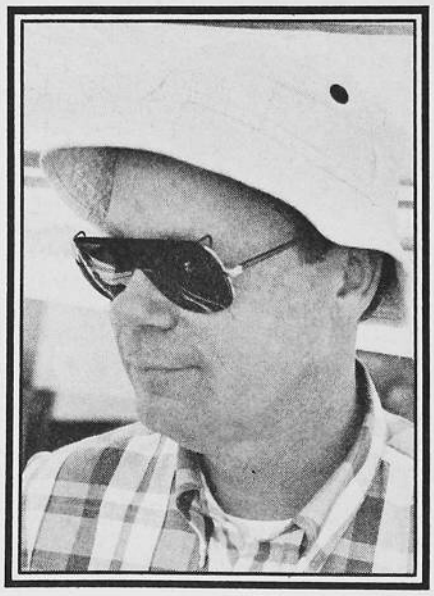


The Faces of Riverside

Left to right, top to bottom: Three and three-quarters comet discoverer David Levy awaiting breakfast in the snow; Ashley McDermott relaxing Monday morning after the fray; Dick Buchroeder admiring some admirable binocular optics; Ben Mayer proposing we convert astrology buffs to amateur astronomers; twenty-year RTMC vet Bob Goff chatting with friends; Randy Wilcox chairing the merit awards committee; Rick Shaffer giving the photographer a dubious look; and big-door-prize-giver John Diebel heading up sales at Meade's booth.







Four-year-old Elizabeth Kenyon won the 8-inch Odyssey donated by Coulter. Already an observer, Elizabeth crowed, "I won my own telescope."

Merit Awards and the 1988 Bozos

Winning Merit Awards were William Phelps, for his binocular tripod; Dewey Burkes, for the design and construction of a 16-inch f/4–f/16 Newt/Cass; Jack Tickner, for a 14-inch collapsible Dobsonian; and Tom Fox for the 12.5-inch f/8 Newtonian described earlier.

For his 10-inch f/6.3 astrophotographic telescope, Carter Roberts; for craftsmanship of his 6-inch f/4 Dobsonian with digital setting circles, Dave Radostevich; and for his novel mirror cell, David Barosso.

The Junior Award went to Robert Quimby, 11 years old, for a 6-inch on a Dobsonina mount, and a special award for an cooperative effort was given the Los Angeles Astronomical Society for its 31-inch.

The merit award committee also recognized Rick Shaffer, for a "disgustingly simple improvement" for small telescope mountings (filling the base casting with epoxy resin); Jack Borde, for an exhibit suggesting that American indians observed the Sun with mica filters; and David Charles, for a dual-axis stepper-motor-driven camera platform.

The Warren Estes Award for the novel use of readily available materials went to Douglas Ostroski for his 17.5-inch f/4.5 Newtonian, and the Clifford W. Holmes Award for contributions to telescope making was given to Kevin Medlock.

Bozo Awards went to Randy Wilcox ("Most Outrageous Attempt to Garner the Edward R. Byers Non-Memorial Award for Overdressing at the Conference"), and an Unknown Bozo award went to the person who drove at high speed through the registration booth in a red Cadillac Seville. "This Bozo is suspected to be an afficionado of multi-turn worm gears," noted the awards chairperson in citing the incident.

The committee commended Gaylord Stockmann for going on Bozo Patrol—and finding that some Bozo decided to start a campfire in the 50-mile winds on Saturday night.

Efficient Mirror Testing

Early in the figuring of a mirror, testing should be quick and need not be accurate. As the accuracy required becomes greater later, the time required to run the test becomes less important. The final test must be as precise as possible and can take a long time to run. Regardless of the stage in the work, however, tests should be made with simple, easily built equipment, such as a Foucault tester.

For the early stages of figuring I use a modification of the Everest shadow test. This test provides the shape of the existing surface rather quickly. While it appears to provide only a crude approximation, this method can be pursued to the point where the error on the wavefront is between an 1/8 and a 1/12 wave.

When this method is exhausted, I turn to a modified form of the Millies-Lacroix test. This gives, with very little additional calculation, an indication of the wavefront error currently existing on the surface.

For the final analysis of the surface I utilize a modified Everest pinstick to improve the precision of the normal zonal test.

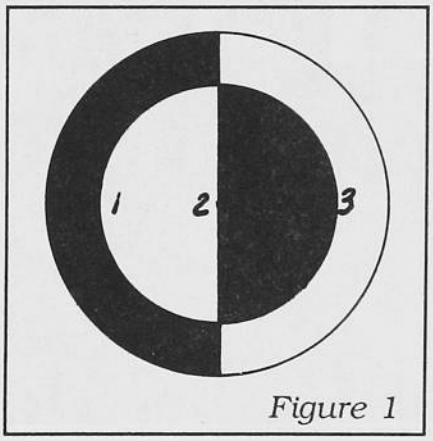


Figure 1

Coarse Testing:
The Everest Shadow Test

Everest studied the positions at which the shadows in the knife-edge test appear for various longitudinal positions of the knife (see *Amateur Telescope Making-I*). He numbered the shadow edges as shown in figure 1.

Everest found the shadow positions for the knife-edge at 50 percent and 100 percent of its full longitudinal travel from the center of curvature. At the midpoint of the knife-edge travel (50 percent), he saw that the location of the doughnut crest (shadow edges one and three) lies at 0.7071 of the radius of the mirror.

He further noted that the first appearance of the shadows on the side opposite the knife-edge (i.e., shadows two and three) occurs at 0.7071 of the distance to the crest, or 0.500 of the radius. As the knife-edge advances toward the axis, this spot enlarges and becomes these shadows.

At the same transverse position the shadow on the knife-edge side of the mirror (shadow one) was at an indefinite distance outside the crest. At the center of curvature of the outside zone the crest was at the mirror edge and the shadows on the side opposite the knife-edge first appeared at 0.7071 of the radius.

Everest continued the discussion of the shadow locations in a brief description of the testing procedure in *Amateur Telescope Making II*. He gave locations for the knife-edge at 70 percent of its travel as 84 percent of the radius. Shadow edges two and three first become visible as a small spot on the horizontal diameter at 0.6 of the radius when shadow one just appears on the knife-edge side of the mirror.

In addition, he noted that shadows two and three appear at 70 percent of the distance to the crest. This is also the fraction of the radius at which shadows one and three merge and the last light disappears from the knife-edge side of the mirror.

These shadow positions work very satisfactorily for small, long mirrors, the only kind that amateurs were making in the 1920s. There is very little correction involved in changing from sphere to paraboloid. As the trend to shorter and larger-diameter mirrors occurred, however, Everest's methods fell into disrepute and were finally forgotten.

The location of the crest, shadow edges one and three are calculated from the familiar formula for a moving source tester:

d=r*r/(2*R)

where d is the knife-edge distance from the central center of curvature. It is measured from that center of curvature and away from the mirror. The quantity r is the radius of the surface at which shadow edges one and three are located when shadow edge two is on the vertical diameter of the mirror. R is the radius of curvature of the surface.

The method can then be extended to any number of additional longitudinal knife-edge positions. The distance to the appearance of shadows two and three, or the merging of shadows one and three, would then occur at 70 percent of the distance to the crest.

While making a 12-inch f/3.4 mirror several years ago, I found that although the shadow positions were correct as nearly as I could estimate them, the zonal test was unsatisfactory. I had not had this experience before and began to suspect the positions as he gave them were not quite correct. I was forced to conclude that the locations given by Everest for the first appearance of shadows two and three were incorrect. These errors become serious when the focal ratio drops below f/5. My analysis of the surface also gave the location of

SHADOW LIMITS

<----- FRACTION OF RADIUS ----->

FRACTION OF K. E. TRAVEL	SHADOWS 1 & 3 SQR(K4)	SHADOWS 1 & 2 MERGE * SQR(K4/3)	SHADOW 3 AT 1-2 MERGER ** 2*SQR(K4/3)
0.10	0.316	0.183	0.365
0.20	0.447	0.258	0.516
0.25	0.500	0.289	0.577
0.30	0.548	0.316	0.632
0.40	0.632	0.365	0.730
0.50	0.707	0.408	0.816
0.60	0.775	0.447	0.894
0.70	0.837	0.483	0.966
0.75	0.866	0.500	1.000
0.80	0.894	0.516	
0.90	0.949	0.548	
1.00	1.000	0.577	
1.5		0.707	

* This column also gives the fraction of the of the radius for first emergence of shadows 2 and 3

** This column also gives the fraction of the radius for the position of shadow 1 at the first emergence of shadows 2 and 3.

Col. 2: If shadows are located at f(r), the theoretical fraction of the knife edge travel is K4 = f(r)*f(r).

Col. 3: If Shadows are at f(r), the theoretical fraction of the knife edge travel is K4 = 3*f(r)*f(r).

Col. 4: If shadows are at f(r), the theoretical fraction of the knife edge travel is K4 = 3*f(r)*f(r)/4.

shadow one at the appearance of these shadow edges. The results of the analysis are given in the table entitled Shadow Limits.

The first column in this table is the longitudinal knife-edge position. This fraction is measured from the crossover point from the center of the mirror to that from the edge of the mirror. The quantity increases away from the mirror.

The second column gives the location of the shadow edges one and three at the time the knife-edge and shadow two are on the axis of the mirror. Shadow edges one and three are commonly referred to as the crest.

The third column gives the location of the first appearance of shadow edges two and three as the knife-edge approaches the axis. This is also the location of the merger of shadow edges one and two after the knife-edge has crossed the axis.

The fourth column gives the location of shadow edge one when the knife-edge has advanced near enough to the axis for the shadow edges two and three to just appear. It is also the location of shadow edge three at the merger of shadow edges one and two.

Everest gives slightly different figures for the location of the first appearance of shadows two and three and for the location of shadow one at that time.

With the information given in this table it is possible to calculate the actual error present on the mirror from the shadow edge locations. This is, however, quite unnecessary in the early stages of corrective polishing. It is adequate to approximate the surface profile by the shadow location method described next. Later, in figuring, use the modified Millies-Lacroix method to calculate actual errors.

A Guide for Figuring:
Shadow Location

Ideally we would like a smooth continuous curve representing the mirror profile to guide our figuring steps. It would be a graph showing the error at every point along the radius. Such a graph might appear as the curved line in figure 2.

But we cannot measure the errors on the mirror. Instead we must measure the slopes on the glass and from them derive the "error curve," or rather its approximation of the error curve, the tangents to this curve (shown as broken lines in figure 2). Although they lack the sophistication of the original curve and might not indicate all of the variations present in the curve, they serve as a guide to the next figuring step.

If there are no differences between the measured and the theoretical knife-edge quantities, then the error curve will be a horizontal line (indciating zero error), and *not* a parabolic curve.

From simple geometry we can see that the highest point on the broken line is usually as high or higher than the curve. The lowest point is as low or lower than the curve. Therefore, if the broken line meets our criterion for the maximum error, then we can be reasonably sure that the actual curve also meets these requirements.

If the shadow edges are located too close to the center of the mirror, for example, then the tangents to the error curve at the predicted and actual locations have a negative slope, that is, the surface falls to the right. If the shadow edges occur farther from the mirror center than predicted, the tangents to the error curve have a positive slope, that is, the surface rises to the right. If the shadow edge occurs at the predicted location, we know that the curve is horizontal.

In using shadow edges to estimate mirror errors, there are a few problems. It would be nice if the shadow edges were sharply defined. Unfortunately they are not. For long-focus mirrors especially, the shadows are faint and the transition from bright to dark is spread over a broad band. In low f/ratios and with large mirrors the transition is more sudden, but considerable uncertainty remains about just where the edge is. We will call the first detectable darkening the shadow edge.

We can make a set of estimates any time we have the mirror on the test stand. For early testing we need only determine whether the slopes are positive, negative, or zero.

Let's do an example. In testing a surface of diameter 5.84 inches, radius of curvature of 56.25, the following conditions were noted. The overall knife-edge move-

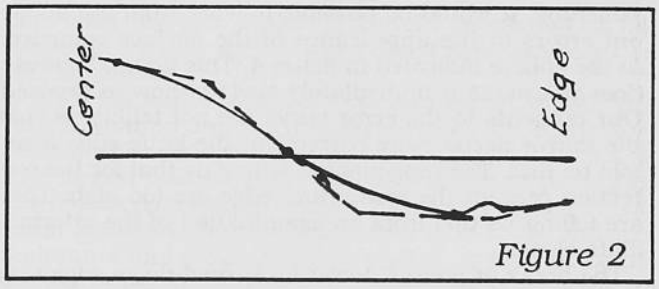


Figure 2

ment at the test was 0.040 inch. The theoretical knife-edge movement for a corrected mirror would be D/(16* (focal ratio)), 5.84/(16*4.8) or 0.076 inch, so the mirror was about 53 percent corrected overall. We show our working graph in figure 3.

The knife-edge was placed at a longitudinal reading of 0.020 inch, or 0.5 of the knife-edge travel for the correction present. We could have used any other fraction, but 0.5 is one where the entire surface of the mirror is covered by the reference sphere. For later tests it will be worthwhile to use additional fractions. At this lon-

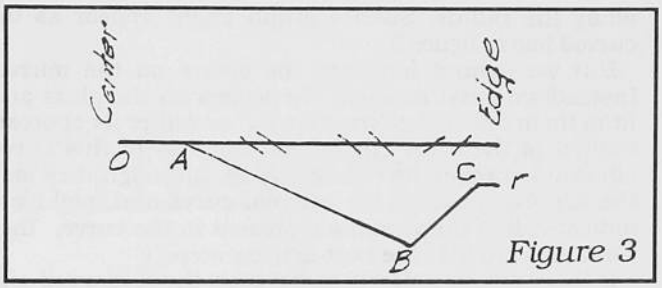


Figure 3

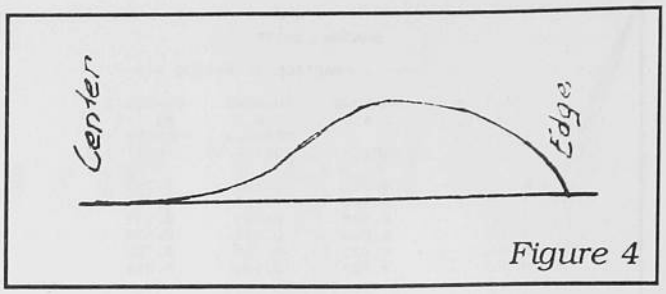


Figure 4

gitudal position the shadow edges one and three were at 0.6 of the radius with the shadow edge two on the vertical diameter. Shadow edge one was at 0.9 of the radius when the knife-edge transverse motion had just caused shadows two and three to emerge to visibility at 0.35 of the radius on the opposite side. Comparing these values with the 0.5 line of the table we see that the first emergence of shadow edges two and three and the location of the crest were too close to the center. Shadow one was located too far from the center.

On a horizontal line we sketch in negatively sloped slashes at 0.35, 0.41, 0.6, and 0.71 of the length from left to right. We also sketch in positively sloped slashes at 0.82 and 0.9 of the length. These slashes are in accordance with our rules concerning the slope of the tangents at these points. We will compare our surface with an ellipsoid that has a 53 percent correction.

The mirror always has a zero slope at the center. Our measurement of 0.040 inch tells us that the slope is horizontal at the edge. Thus, the slope changes somewhere between the center and 0.35 of the radius and between 0.9 and the edge. We use about one half of these values and start a negative sloped line at about 0.17 from the left end. Our slashes show the direction of the slope and indicate that the line should continue to about halfway between 0.7 and 0.82. From this point to about 0.95 of the length our slashes indicate we should draw a positive slope. The knife-edge measurement tells us that from about 95 percent of the length to the end the slope should be horizontal.

Some workers may be bothered by the use of only one slope in the very long segment between points A and B and the positive segment between B and C. It is true there are probably differences in the slopes at the shadow edges. We do not care at this stage of corrective polishing. It would be possible to work from the apparent errors in the appearance of the surface compared to the sphere indicated in figure 4. This figure, however, does not make it immediately obvious how to proceed. Our tangents to the error curve are not telling us that the mirror needs more correction: the knife-edge travel told us that. The tangents are telling us that for the correction present the center and edge are too high. They are telling us this from an examination of the intermediate slopes.

The break at point C toward a turned-down edge may or may not be significant at this time. It is a fairly simple matter to reduce the curvature at this point if desired. Such a reduction will tend to reduce the overall correction but will do nothing for the misplaced shadow edges at the crest and at the point of emergence of the shadow two-three.

This process, after being used a few times, becomes an entirely mental one. On determining the shadow edge locations, the worker will realize that the additional correction needed should be mildly concentrated within about 0.75 of the radius of the mirror. If on a subsequent examination of the mirror the shadow edges have moved closer to the predicted locations, the shape has been improved.

When the overall knife-edge travel is correct and the shadow edges are located at the predicted locations for several lines of the table, I consider the first stage of corrective polishing complete. When these conditions are met, the mirror is probably better than competitively priced commercial surfaces and usually much better.

The Modified Millies-Lacroix Reduction

One of the more important recent developments in the field of amateur mirror making was the introduction of the Millies-Lacroix reduction method (see *S&T*, February 1976, p. 127). The test is based on that of Texereau. Texereau gave the relation:

l(i) = L(i)*r(i)/(4*f)

in his equation #16. Here, for the ith zone, l(i) is the transverse aberration at the focus, r(i) is the radius of the zone, and f is the focal length of the mirror. The quantity L(i) is:

L(i) = (knife-edge reading
-theoretical knife-edge reading
-a suitable constant).

Millies Lacroix substituted the quantity:

(rho) = 1.22*(lambda)*(f/D),

the radius of the first dark ring of the stellar diffraction pattern, for the transverse aberration, l(i), and lambda is the wavelength of the light, and solved the equation for the maximum value of the quantity:

L(i,max) = 2*R*(rho)/r(i).

Here R has been substituted for 2*f. This form is for the fixed-source test device. With a tester where the source moves with the knife-edge the value is one half of this or:

L(i,max) = R*(rho)/r(i).

This sets a maximum limit for the knife-edge reading such that if L(i) is equal to or less than the appropriate choice of the last two expressions, the zone tested represents a diffraction limited zone. When all zones pass the test, the mirror is diffraction limited.

It is very important that the correct choice of the expressions be made. If the readings were made with a tester with the source moving with the knife-edge, the second expression for L(i,max) must be used. If the tester is one with a fixed source, it is probably simplest to use the second expression after DIVIDING the knife-edge readings by two. The theoretical knife-edge readings, TKER(i), then become those for a moving source tester:

TKER(i) = r(i)*r(i)/(2*R).

Millies-Lacroix proposed plotting these limits as curves, then graphically checking whether the knife-edge measurements represented a diffraction limited surface. He presented two methods of plotting the curves. In the first the values of L(i,max) were added to

and subtracted from the knife-edge theoretical values for each point to be plotted. The raw knife-edge readings were plotted and moved vertically to test whether all values could be placed between the curves. If the points fell within the curves, the mirror was diffraction limited and satisfied the first criterion of Danjon and Couder.

Alternatively, he proposed plotting the positive and negative values of L(i,max) against the radius of the mirror. This gave a pair of rectangular hyperbolas for the limits. The curves were equal and symmetrical about the horizontal axis. The knife-edge readings were diminished by the theoretical knife-edge readings before plotting so only the differences appeared. In either method it was necessary to plot new curves for each mirror.

The modifications of the Millies-Lacroix method I use consists of two parts. The first is an extension of the method to permit the direct calculation of the wavefront error. This is convenient because it assures that the wavefront error is calculated for the same focus for which the mirror is diffraction limited. It is also convenient because very little additional calculation is necessary. The second is a change in the scaling to permit using one set of limits for all mirrors.

Texereau used the following form for the slope of the wavefront for zone i:

u(i) = -L(i)*r(i)/(R*R).

for a test device where the source is fixed. For a moving source tester the quantity becomes:

u(i) = -2*L(i)*r(i)/(R*R).

The rise or fall on the wavefront across the zone is:

rise(fall) = -2*L(i)*r(i)*w(i)/(R*R)

where w(i) is the width of zone i.

We continue to perfect the mirror until the knife-edge readings are such that L(i) is equal to or less than L (i,max). We can thus write:

L(i) = K2*L(i,max)

where K2 is equal to or less than 1. The quantity K2 can be read from an appropriate scale.

If we make appropriate substitutions for L(i,max) and L(i) and simplify, our rise or fall becomes

rise(fall) = (-1.22*w(i)/(2*r))*K2*(lambda).

If we define

K1 = -0.61*w(i)/r

and also make the unit of measurement of the error equal to the wavelength, the equation becomes

rise(fall) = K1*K2.

This is a very simple calculation. We simply sum these quantities across the mirror to get the wavefront error.

The Millies-Lacroix limits are quite small. To use any graphical method, they must be expanded by selecting a scaling factor to make the limits visible. Millies-Lacroix used an arbitrary factor to expand the plot so the knife-edge readings could be determined to be inside or outside the limits.

The quantity L(i,max) defined above may also be written:

L(i,max) = 4.88*(lambda)*(f/D)*(f/D)/(r(i)/r).

This quantity has two variables, (f/D) and (r(i)/r). Here r is the radius of the mirror. If we were plotting the curves as did Millies-Lacroix in his alternate method, we could plot the radius of the mirror as the horizontal unit and plot the limits against (r(i)/r), thus standardizing the horizontal dimension.

Because the wavelength is a very small number, I have found it convenient to use a scaling factor of 10,000/((f/D)*(f/D)) for plotting the limits, L(i,max). Once plotted, these Millies-Lacroix limits serve for any mirror.

I mentioned earlier that the values of K2 could be read from a suitable scale. I have also found it convenient to replace the original Millies-Lacroix curves with a series of scales. The scale for zone i is proportional in length to the limit, L(i,max). Each scale is divided into ten units, which enables me to estimate the value of K2 to one-half unit or the nearest one twentieth of the limit. Such a set of scales is shown in figure 5.

The scales I use are for equal area zones and the values of r(i) are those recommended by Couder. The method of calculation of the values is given in the example. In the scales I have used a wavelength of 19.685E-06 inches. This gives a slightly conservative estimate of the error.

If we adjust the position of the scales so the maximum positive and maximum negative readings for the various zones are equal, we have found the best focus for the current surface. The individual scale readings are the values of K2.

This enables us to calculate an estimate of the tangents to the error curve by using the fractions of the M-L limits. I split the calculations into two groups: preliminary and interim. The first is necessary only one time for a mirror; the second is necessary for each determination of the surface quality.

Let's return to the example used for the Everest Shadows (see the M-L Worksheet figure). We start to calculate columns 1 and 2, the preliminary calculations, by finding the quantity r*r/(2*N) where N is the number of zones, in this case seven. This quantity is then multiplied by each integer from 1 to 2*N. The square root is then taken of each of these products. If the whole number multiplier is odd, the square root goes in column 1. If the multiplier is even, the square root goes in column 2. Column 3 is simply the square of the number in column 1 divided by twice the radius of curvature. This is our theoretical knife-edge movement for each zone. Column 4 is the width of each zone divided by r and multiplied by -0.61. This is the K1 value for each zone.

In the interim calculations, column 1 is the average of the knife-edge readings for the individual zones. Subtract the readings of column 3 of the preliminary calculations from column 1 of the interim calculations, and then multiply the difference by 10,000/((f/D)*(f/D)), our scaling factor, to obtain column 2 of the interim calculations. Column 2 is the quantity plotted for comparison with the M-L scales; it should be plotted to full scale, in inches, with a suppressed zero as shown on the worksheet.

With the scales overlaid, read and record the K2 values in column 3 of the interim calculations. Remember to shift the overlay so the largest negative K2 is equal to the largest positive K2. These K2s are each multiplied by the corresponding values of K1 and entered in column 4. Column 5 is the line-by-line sum of the values of column 4 and is the quantity plotted as the end points of the tangents to the error curve. The quantities are plotted at the outside of the zone edges, column 2 of the preliminary calculations.

Balancing the maximum positive and maximum negative K2 values is equivalent to Texereau's choice of the constant in line 9 of his calculations. It assures that you find the best focus for the surface.

The individual points are then connected to give the tangents to the error curve. The example represents the minimum error limit for the Everest method for a mirror of about f/5. The slopes shown here represent about a 4 percent error in estimating the shadow edge positions.

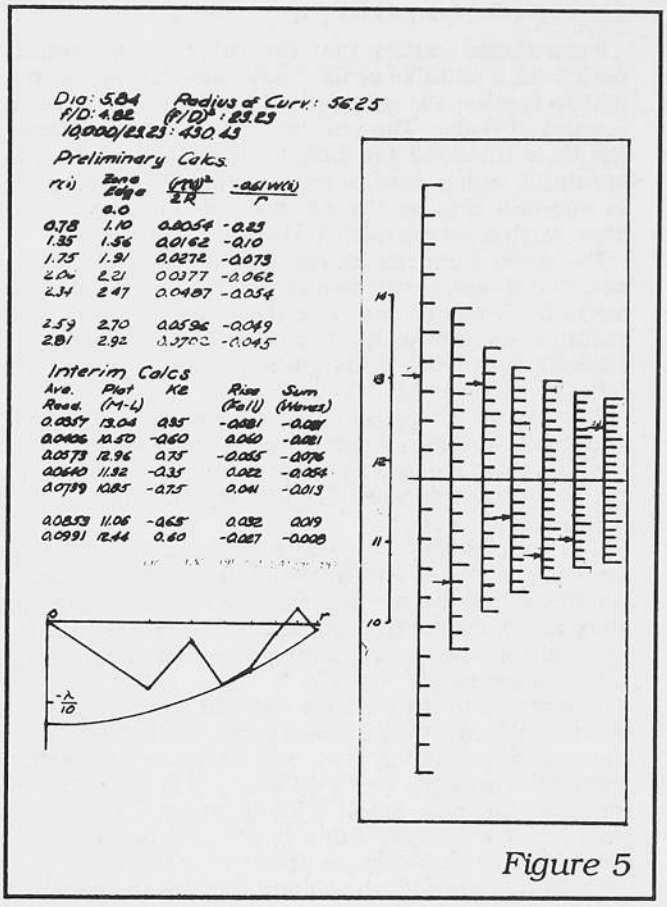


Figure 5

The wavefront estimate indicates an error of about 1/10 wave from the highest point to the lowest on our tangents. Remember this error is on the wavefront.

Texereau recommends drawing a parabola to reduce this estimate. He said we have a right to refocus to the best wavefront. But there is the rub. We have chosen a focus by balancing the K2 maxima that gives the minimum transverse aberration at the focus, the best focus.

Dick Suiter in his "Method of Exploratory Focus" (see TM#32) indicates that Texereau's procedure, if not wrong, is at least questionable. If the parabola drawn in for an improved wavefront error estimate begins and ends close to the original horizontal axis, there is probably no harm done. However, if the curve begins or ends far from the axis we have, in effect, changed the focus significantly. While the improvement may be dramatic, there is no guarantee the mirror is diffraction limited.

In the example we see a mirror that has about 1/10 wave error on the wavefront at the minimum transverse aberration. Because each of the K2 values turned out to be within the M-L scale length, the mirror meets both criteria of Danjon and Couder.

The mirror, however, has some rather steep slopes indicated by our estimates of the tangents. Every zone, save the first, contributes to the shortening of the focal tolerance. Any time the absolute value of K2 is larger than the quantity (1-(r(i)/r)), the aberration in that zone shortens the focal tolerance. With a focal ratio of about f/5 the focal tolerance is very small even for a perfect surface.

Because it is not possible to add glass to the mirror, we can only reduce the high zones. If we draw a parabola as in Texereau's method, so it is below the lowest point on our estimated tangents, points at the outside edges of zones 3 and 7, and crosses the vertical axis horizontally, we can easily see the strategy for the next polishing session. (In drawing this parabola, we are not refocusing to give an improved estimate of the wavefront error, but to determine the simplest figuring strategy.) To bring the surface to the drawn parabola, we will deepen the center, and at the same time smooth the zone 2 and 3 combination to reduce the error.

This work must be done cautiously as we only wish to lower the center about 1.3 millionths of an inch. In my experience, if we reduce the center and the zone 2 and 3 combination to this parabola without touching the edge zones, the next analysis would indicate the edge had rolled. Therefore, I would also soften zones 6 and 7 in the next work session.

The K1*K2 Method

The K1*K2 method of analyzing a mirror surface lets us examine the maximum error for a diffraction limited mirror, one such that all zonal measurements fall within the Millies-Lacroix limits. For such a "barely diffraction limited" mirror the maximum possible value of K2 is 1 and the minimum possible value is -1.

Suppose a mirror has zones with K2 values alternating between +1 and -1. Our tangents to the error curve form a saw-toothed profile, and the maximum error is equal to the rise or fall across the widest zone.

Because the maximum absolute value of the K2s is 1, we have no right to draw a parabola to improve our wavefront estimate. We will first use a limit for the width of the first value, K2 = +1, of one half of the radius of the mirror. This makes the width of the remaining surface also one half of the radius. The value of K1 then becomes:

K1 = -0.61*(0.5*r)/r

K1 = -0.305

Because our first value of K2 is +1, the estimate of the tangent to our error curve will start at zero and fall to a value of -0.305 wavelength at the center of the radius. At this point the value of our K2 changes to -1, and the estimated tangent to the error curve rises to zero at the end of the radius. (See figure 6.) We have the possibility of an error as great as almost a third of a wave on the wavefront for a "barely diffraction limited mirror," a mirror that is at the Millies-Lacroix limit.

We have a slightly different condition here than in measuring a mirror. On such a mirror we choose a few specific radii that we measure. We then determine the K2 corresponding to the measurement. Here we have assumed that K2 is +1 for a portion of the radius. The tangent under this condition is also the error curve. This possible error is rather surprising in view of the fact that the Millies-Lacroix limit is often equated with the 1/4-wave error limit.

But this is not the maximum limit possible for a mirror that meets the Millies-Lacroix limit. If we make the change from a positive value of K2 to negative value K2 at 3*r/4, the error increases to 0.46 wave on the wavefront. (See the second sketch in figure 6.)

Indeed, if the change in K2 is far from the center of the radius as indicated in the third set of sketches in figure 6, the error approaches 0.61 wave on the wavefront. This is a far larger limit than normally stated for mirrors at or within the Millies-Lacroix limit. Here, again, the best reference parabola is the horizontal axis, as any refocusing would violate our "barely diffraction limited" condition.

These figures represent mirrors that are very unusual.

No mention of the size and focal ratio of the mirror has been made, so the errors indicated can apply to a mirror of any dimensions. Low focal ratio mirrors are more apt to have one of these conditions than mirrors with longer focal ratios. With very low focal ratios the original Millies-Lacroix limits become comparable with the error in measuring zones, particularly in the outer zones. The mirrors are unusual in that we have postulated that every point up to a particular fraction of the radius has a K2 value of exactly +1 and from that point to the edge has a K2 value of exactly -1. No self-respecting observer of the shadow motions would even be measuring such a mirror.

For reasonable mirrors in which the K2 value varies uniformly from +1 to -1 (as in the fourth pair of sketches in figure 6), the limit of the error quickly becomes less than 1/4 wave. In the sketch the range is 0.3*r and the wavefront error is almost exactly 0.25 wave. We would have to conclude that the association of the 1/4-wave limit with the Millies-Lacroix limit is probably justified many mirrors -- despite the examples above.

Final Testing:
Measurement with a Pinstick

For making the final estimate of surface quality, I adopted a method that does not use a Couder mask -- the pinstick method. This test locates the radius under test.

To do this test, tape satisfactory diameter pins to a narrow stick at the radii computed in the preliminary calculation. Support this assembly in front of the mirror so the vertical pins cross the horizontal diameter of the mirror. Bring the knife-edge toward the returning cone of light. As you view the mirror past the knife-edge, the pins will change from dark on a bright background to bright against a slightly less bright background. During this transition in appearance there is a transverse knife-edge position where the pin appears to match the background light intensity. It disappears.

Now compare each pin with its opposite number. If the pin on the knife-edge side of a zone has disappeared, the pin on the off side can be leisurely examined. If it appears bright, the knife-edge should be moved closer to the mirror. If it appears dark, the knife-edge is too close to the mirror. When both the on-side pin and the off-side pin are invisible, the longitudinal knife-edge position should be recorded as a measurement for the zone.

The size of the pins is critical, and the search for satisfactory pins is sometimes frustrating. Test pins with the pinstick in front of the mirror. Advance the knife-edge to the returning cone until there is a barely perceptible darkening of the entire surface. Before this darkening, the pins appear dark against the bright mirror surface. After the darkening, the pins will have acquired bright diffraction lines on each side. If the pin is too large, you will see two bright lines; the diameter must be such that the two lines blend into one. If the pin is too small, the test seems to lose sensitivity.

For my eye and basement lighting I prefer a pin that subtends an angle at the knife-edge of about 45 arcseconds. For a 6-inch f/8 this works out about 0.021 inch in diameter. For pins for mirrors with radii shorter than this, try wire from some discarded electrical equipment. Some of this is quite small in diameter.

Some individuals have exceptional sensitivity to minute differences in light intensity combined with very acute vision: for them the pin may not disappear continuously. They will see a pin that has the same apparent brightness as the general background near the pin but surrounded by a slightly darker narrow band at the pin edge. If the intensity seen for the pin is matched to the background a couple of pin diameters away from the center, the test will still be successful.

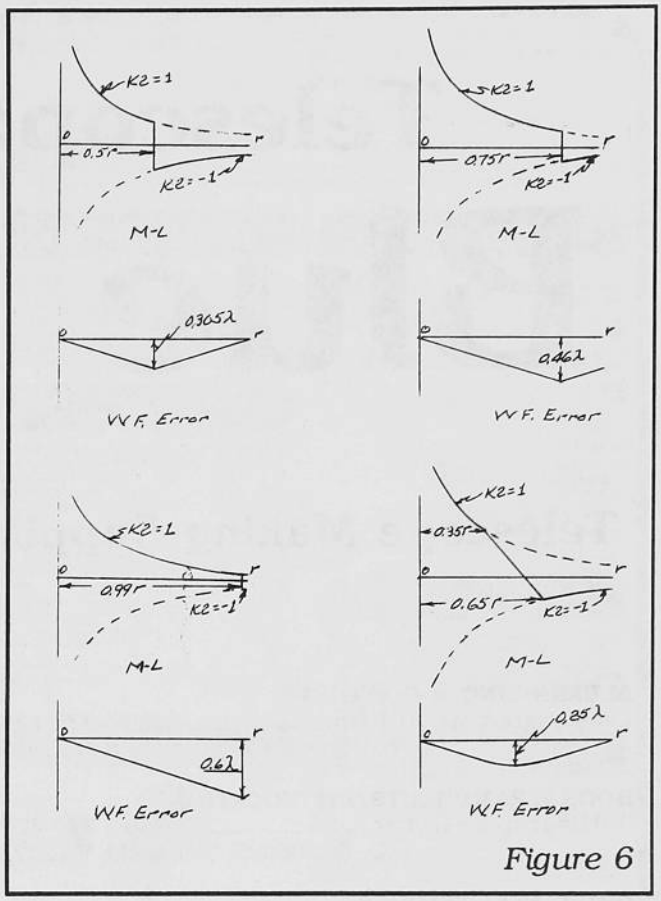


Figure 6

With a Couder mask we must compare illumination intensities separated by as much as the mirror diameter. In fact the most important intensities are separated by nearly this amount. With the "blinking" pins on the pinstick the intensities to be compared are adjacent or very nearly adjacent. The method is capable of nearly eliminating the differences in knife-edge readings for a zone.

The pinstick test is a tedious one to perform, and the transverse motion of the knife-edge must be very delicately controlled. However, I feel the improvement in precision is worthwhile for the final estimate of surface quality. To reduce the measurements, I use the modified Millies-Lacroix analysis, except that I find the individual values of K2 analytically rather than graphically.

Thus the mirror is completed with a very precise test. Early in figuring I estimate the tangents only to being positive, zero, or negative with the Everest Shadow position method. When that method ceases to be effective, I measure and compute the tangents with the modified Millies-Lacroix method and use the information to plan the next polishing session. I use the blinking pin test for the final measurement of the wavefront error.

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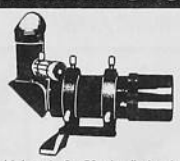

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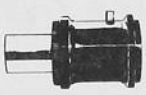

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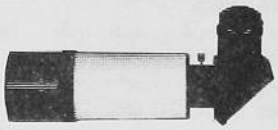

This all new University 8x50 viewfinder uses standard 1¼" eyepieces. The cell, tube, and eyepiece holder are metal for years of service. Don't confuse this unit with those made mostly of plastic! Comes with 1¼" star diagonal, and 1¼" wide-field Kellner with crosshair. Fully-coated achromatic 50mm objective lens. Mounting bracket is extra. Choice of black or white finish.

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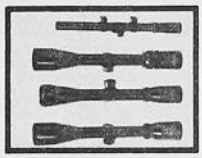

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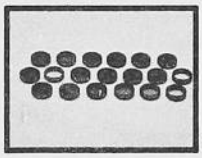

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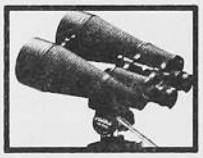

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Focal Length	Barrell Diameter	Field of View	Para-Focal	Sug. List	Wholesale to Customer
7.5mm	1¼"	52°	Yes	130.00	$69.00
10mm	1¼"	52°	Yes	130.00	69.00
15mm	1¼"	52°	Yes	130.00	69.00
20mm	1¼"	52°	Yes	140.00	79.00
25mm	1¼"	52°	Yes	140.00	79.00
30mm	1¼"	52°	Yes	180.00	89.00
35mm	1¼"	49°	No	200.00	89.00
3.8mm	1¼"	52°	Yes	240.00	129.00

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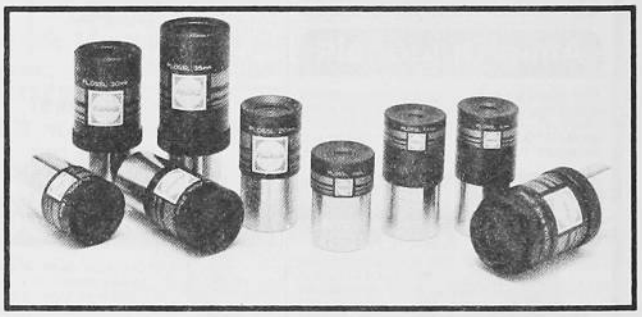

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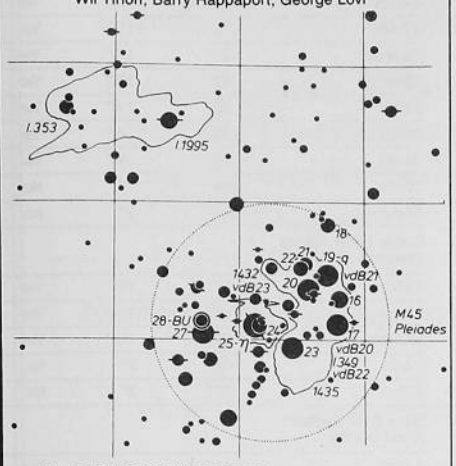
URANOMETRIA 2000.0

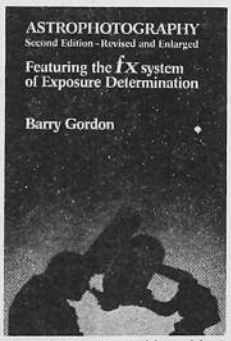
Volume 1—The Northern Hemisphere to −6°
Wil Tirion, Barry Rappaport, George Lovi



Why is URANOMETRIA 2000.0 Volume 1 meeting with such success? Judging from the many letters we have received from happy customers it all boils down to the fact that between its covers more labeled stars and deep-sky objects have been packed than any other atlas in history—and it is presented in a truly user friendly format.

Because URANOMETRIA 2000.0 Volume 1 has so much to offer must it be for "experts" or people with mammoth scopes? Not so (even though there is plenty to challenge the "big scope crowd") hundreds of objects are within the reach of night binoculars! All of this is in a format that tucks under your arm and allows you to skip over huge segments of sky like leafing through a book. In fact besides being an atlas, it may also be the ultimate "cloudy night" book. One can spend hours just leafing through the hundreds of charts and leisurely studying the fully labeled objects.

☐ **URANOMETRIA 2000.0** Vol. 1 ..... **$39.95**



Dennis di Cicco wrote in the December 1983 *Sky and Telescope* "Perhaps the most innovative section of the book is Gordon's approach to determining the correct exposure. He has developed what he calls the "*fx* system," whereby the basic elements of film speed, exposure duration, and f/number are assigned simple numerical values. Each scene, whether a daytime landscape, the Moon's surface, or Jupiter, is given an *fx* value for the appropriate exposure. It is a simple matter to add the appropriate values of different elements to arrive at the correct *fx* for the scene...I was impressed with Gordon's *fx* values for photographing objects like M27 and M57. Working through the simple formula described earlier, I found that some of my best exposures correspond closely to *fx* values recommended in the book... Overall, *Astrophotography* is an excellent book with a lot to offer." Now this 2nd edition has been revised and enlarged with more than 75 photographs (many full page), 32 tables and 7 line drawings. If you are new to astrophotography this book will get you going with good results right from the start.

☐ **Astrophotography—2nd Edition,** Gordon **18.95**

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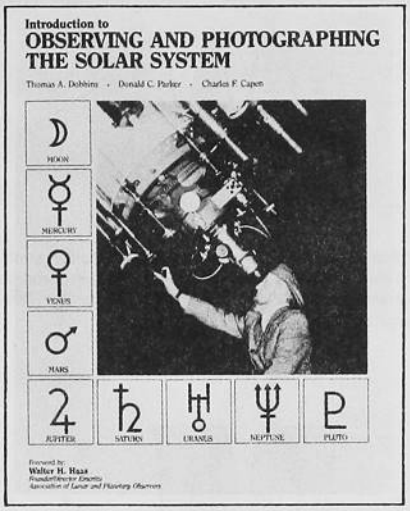

This book tells you how, with a modest telescope even in a light polluted city, to observe and photograph the Moon and planets—and in so doing collect data of scientific merit. Donald Parker fully describes his equipment and techniques that enable him to take photographs that *Sky and Telescope* magazine praised: "Using a 12½-inch f/6.5 Newtonian reflector at his home in Coral Gables, Florida, Parker often obtains images that equal the best made by professional astronomers using much larger telescopes at mountaintop observatories." Thomas Dobbins has been an avid observer for many years and his work has appeared in a number of journals and popular magazines. During his lifetime, Charles Capen was a recognized expert on the planet Mars and much else dealing with observational aspects of the Solar System.

Walter Haas wrote the Foreword which reads, in part: "The book is, then, an invitation to the owner or future owner of a telescope to make his observing efforts more effective, and hence more enjoyable and more useful. Yet this book is also much more. The armchair astronomer, who prefers to observe from his cozy living room (no mosquitoes, no wind, no freezing temperatures, no dew, and no irksome intruders), will find much informative reading. The historian of science will encounter many poorly known incidents from the past of astronomy. The careful student will discern numerous examples of the successful application of the methods of science."

Walter H. Haas
Founder/Director Emeritus
Association of Lunar and Planetary Observers

Overall, this 8½ by 11-inch book contains 224 pages, 15 chapters, 5 Appendixes, Index, plus over 200 photographs and drawings. Available mid-April 1988.

☐ **Introduction to Observing and Photographing the Solar System** Dobbins, Parker, and Capen **$19.95**

ATLASES AND CATALOGUES

☐ **Uranometria 2000.0, Vol. 1 Northern Hemisphere to −6** Tirion **39.95**
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REFERENCE

☐ **Astronomical Almanac 1988** USN **21.00**
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ASTROPHOTOGRAPHY

☐ **Astrophotography II** Martinez **18.95**
☐ **Astrophotography—2nd ed.** Gordon **18.95**
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COMING SOON

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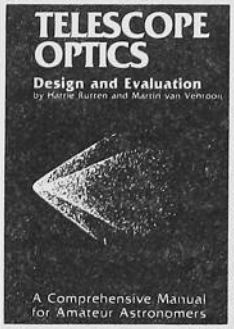
This book will both arouse your curiosity and answer your questions. Why are there so many different kinds of telescopes? What does each type have to offer? What makes one telescope better than another? Which are best? Why? What are the tradeoffs? As a telescope buyer, you will be better informed; as a telescope maker, you will be able to design custom optics.



Many readers will find the analyses of existing designs the most valuable part of the book. Newtonians, Cassegrains, Maksutovs, Schmidt cameras and more are described and analyzed so that you can easily compare them. What's your dream telescope? This book will help you choose it.

Others will make use of the power they now have to check, test, and analyze new telescope designs. The design and raytrace programs available as an option to this book will give you the tools you need to begin with a basic design and work systematically until you have created an optimized optical system that meets your personal design criteria. You'll be able to try new types of glass, design a telescope around that corrector shell you have parked in the basement, even compare the performance of many different eyepieces on your telescope.

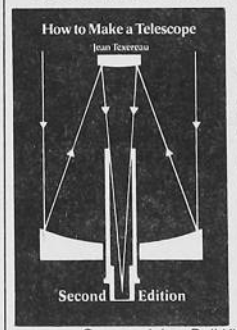
No longer must you, as an amateur astronomer, meekly accept someone else's opinion about a telescope design. You can scrutinize existing designs and improve them to meet your own standards. Is that new astrographic camera all it's cracked up to be? By raytracing it, you'll know the answer.

☐ **Telescope Optics, Evaluation and Design,** Rutten and van Venrooij **$24.95**
☐ **Telescope Optics Software,** IBM-PC with EGA or CGA (sold only to purchasers of the book) **$24.95**

Available mid-July 1988

This book is the first how-to-do-it book for microcomputer control of small- and medium-sized telescopes. It devotes entire chapters to control theory, motors and their controllers, angle sensors, astronomical and mechanical corrections. The authors have sought to make this book a complete, single source of information and it is based upon their hands-on experiences with automated telescopes. One of the systems described does fully automatic photometric measurements of over 100 different stars each clear night. Over 140 illustrations, schematics, and flow diagrams provide all the detail you need to duplicate the systems described or to begin your own unique design. Includes complete software listings in Apple BASIC and BASIC09.

☐ **Microcomputer Control of Telescopes,** Trueblood and Genet **19.95**



For nearly 30 years the first edition of this book has been considered by many to be the best guide to making a Newtonian Telescope. The author takes you step-by-step through the process of grinding, polishing, testing, and installing your mirror in a tube on either an altazimuth or equatorial mount. This new edition with over 300 more pages now has entire chapters on making a Cassegrainian, optical windows, equatorial mounts, computer programs in generic BASIC for the reduction of Foucault test data and the design of two mirror telescopes — Cassegrainian, Dall-Kirkham, Pressmann-Carmichel, and Ritchey-Chretien. Also included are comprehensive bibliographies from *Sky and Telescopes* "Gleanings", *Scientific American* and *Telescope Making* magazines. *Astronomy* magazine's reviewer said "...the book has that same feeling of total mastery as the original...With this book, you have every chance of building what Texereau calls "a telescope that is optically beyond reproach".

☐ **How to Make a Telescope—2nd Edition,** Texereau **19.95**

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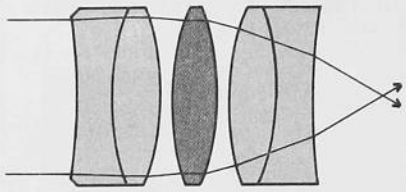
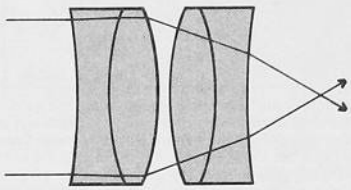
Design Specifications: Meade Series 4000 eyepieces yield the widest possible fields of view, consistent with pinpoint edge-of-field sharpness and long eye relief, and yet with extremely low astigmatism, spherical aberration, and off-axis color. Incorporating 7-layer multi-coatings and edge-blackened optics for optimal image contrast, these sophisticated 5- to 8-element designs permit levels of optical corrections virtually impossible to achieve with eyepieces of fewer elements. The polished chromed-brass barrels are threaded for standard filters, and, where practical (see table), eyepieces and both Barlow lenses are parfocal, allowing eyepiece interchangeability without refocusing.

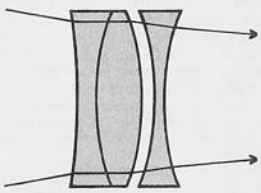
Eyepiece Groups: Eighteen focal lengths in the three Series 4000 eyepiece groups permit precisely the right eyepiece for any application. Whether your telescope is an f/4 Newtonian, an f/10 Schmidt-Cassegrain, or an f/16 refractor,



Meade 5-element Super Plössl design: the central lens element enables significant reductions in chromatic aberration and edge-distortions over other premium Plössl designs.



Other premium Plössls: include only the traditional 4-elements.



Meade Series 4000 Barlows: 3 elements, air-spaced, instead of the standard 2 non-air-spaced elements.

Series 4000 Eyepieces and Barlows

Super Plössls (5-elements)	APPARENT FIELD	BARREL DIA.	PARFOCAL
6.4mm	52°	1¼"	Yes
9.7mm	52°	1¼"	Yes
12.4mm	52°	1¼"	Yes
15mm	52°	1¼"	Yes
20mm	52°	1¼"	Yes
26mm	52°	1¼"	Yes
32mm	52°	1¼"	Yes
40mm	44°	1¼"	No
56mm	52°	2"	No
Super Wide Angles (6-elements)			
13.8mm	67°	1¼"	Yes
18mm	67°	1¼"	Yes
24.5mm	67°	1¼"	Yes
32mm	67°	2"	No
40mm	67°	2"	No
Ultra Wide Angles (8-elements)			
4.7mm	84°	1¼"	Yes
6.7mm	84°	1¼"	Yes
8.8mm	84°	1¼" & 2"	Yes
14mm	84°	1¼" & 2"	No
Barlow Lenses (3-elements, air-spaced)			
#140 2X Telenegative Amplifier		1¼"	Yes
#142 2.8X Telenegative Amplifier		1¼"	Yes

Meade 2" Mirror Diagonal: For attachment to Schmidt-Cassegrain telescopes, the 2" Mirror Diagonal permits use of Series 4000 eyepieces with 2" barrels. The 1/10-wave-flat Pyrex mirror, manufactured at the Meade Costa Mesa optical facility, is multi-coated with enhanced aluminum for maximum reflectance. An adapter for 1¼" eyepieces is included.

Where To Buy: Meade Series 4000 eyepieces and Barlows are available from over 600 authorized

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Super Wide Angles: These 6-element eyepieces, with their 67° fields, offer exquisite wide-angle images at low to medium powers, ideal for star fields, galaxies, and other deep-space phenomena. Focal lengths with 1¼" barrels yield extremely high-resolution, high-power lunar and planetary images when combined with one of the Series 4000 Barlows.

Ultra Wide Angles: The ultimate in modern eyepieces, Meade 8-element Ultra Wide Angles permit extreme image fidelity and sharpness over an amazing 84° apparent field: for moderate to high power applications, no other eyepieces come close. A magnificent optical match with Schmidt-Cassegrains and fast Newtonians.

Series 4000 Barlow Lenses: The most sophisticated Barlows ever developed for commercial telescopes, these 2X and 2.8X Telenegative Amplifiers include 3-element, air-spaced, multi-coated optics, unmatched in image resolution and color correction. Both models optically complement the Series 4000 eyepieces, while significantly enhancing the performance of other eyepieces as well.

Meade dealers in the U.S.A. and Canada. Call us toll-free (see below) for your nearest dealer.

Prices: Notwithstanding their performance standards and optical sophistication, Meade Series 4000 eyepieces and Barlows are priced very competitively with other premium oculars and Barlows.

Warranty: All Series 4000 systems are covered by the Meade Limited Lifetime Warranty—the most extensive in the industry. See the Meade catalog for details.

New 1986 Meade General Catalog 86-R: $3.00

Just-published, the new Meade 1986 General Catalog includes complete information on the full range of Meade astronomical products, along with a supplement on **"How To Choose Your Eyepieces."** Send $3.00 for your copy.

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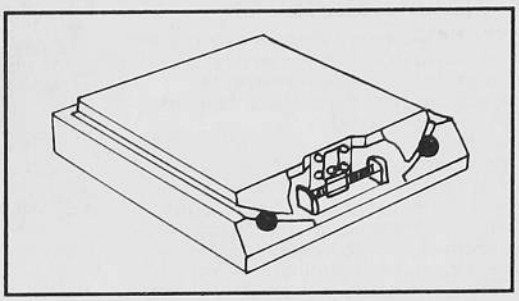

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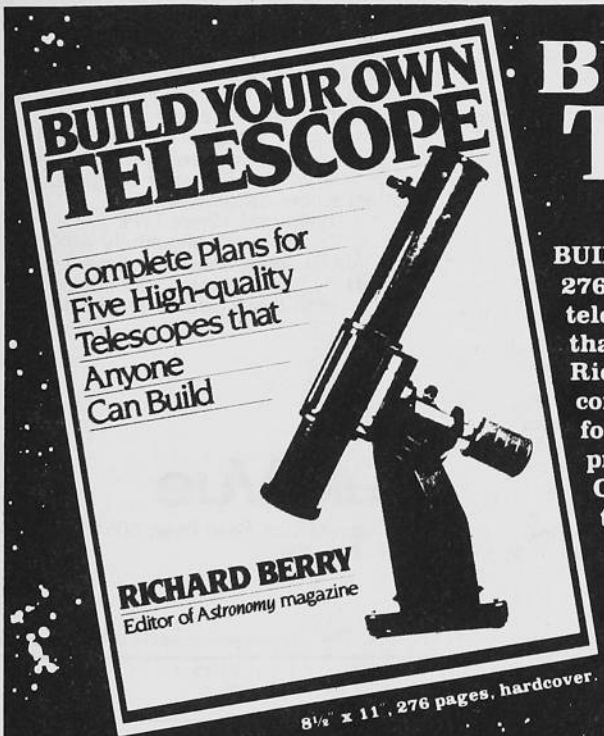

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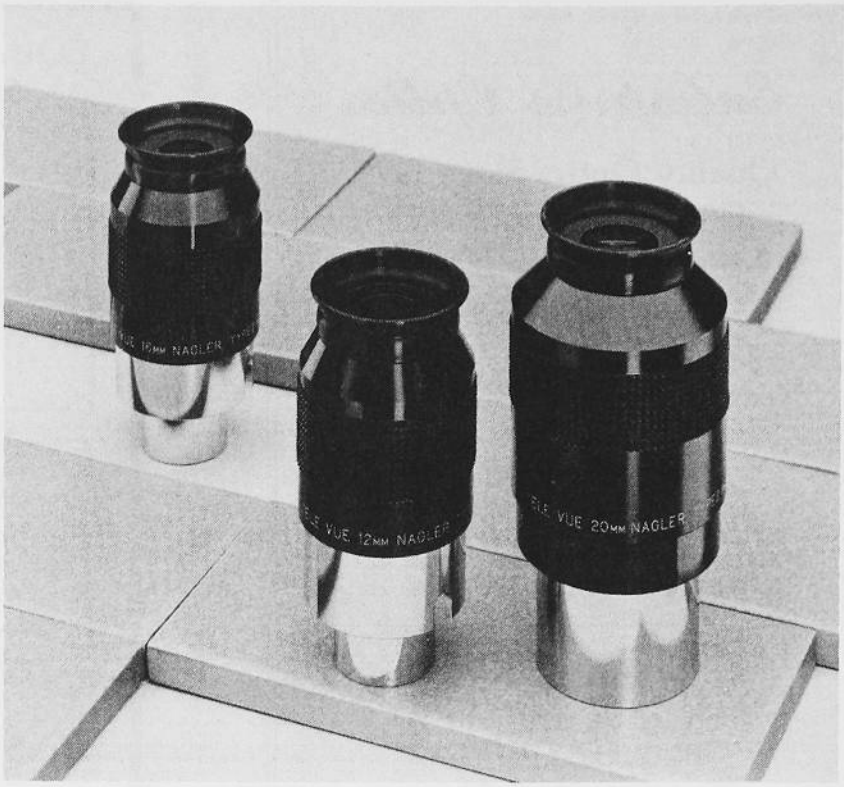
Tele Vue

NAGLER TYPE 2 82° FIELD EYEPIECES



These new 8-element designs extend the Nagler concept to impressive new performance levels, while retaining the basic advances of the original Naglers:
—82° apparent field
—Full field correction
—Fast aperture correction

New Features Include:

First, three new focal lengths, 12mm, 16mm, and 20mm extend the concept to unprecedented wide viewing fields.

Second, full exit pupil correction permits comfortable night and day use.

Third, fold-down rubber eyeguards are included for maximum comfort and dark adaptation.

Fourth, relatively lightweight and moderately sized, they also have knurled rubber grip rings for easier handling.

Design Goals

The basic Nagler series has already achieved image correction 10 times better than previous wide angle eyepieces (study in "Telescope Making" titled "The Nagler 13, a Remarkable Telescope Eyepiece"). We felt that trying to extend the apparent field or image correction levels beyond that of the original Nagler series would NOT yield significant practical gains, but that extending the focal lengths WOULD offer enormous potential for spectacular low power, wide-angle viewing. After all, Tele Vue Wide-Field eyepieces have already proved the value of low power 65° viewing with important improvements in image sharpness.

What were the barriers to simply scaling up the original Nagler designs to longer focal lengths?

Two practical limits had to be overcome:

1) Substantial physical size, weight, and cost increases would be impractical.
2) Scaling up exit-pupil aberrations would be unacceptable in our judgement. Although the original Nagler eyepieces provide extremely sharp IMAGES, exit-pupil aberrations require a large (nighttime) eye pupil opening to encompass the full field. For this reason, daytime viewing with the 13mm Nagler is not recommended. Eye positioning is just too sensitive with this design to consider focal lengths longer than 13mm. The 9mm and shorter Naglers don't show this sensitivity.

Nagler Type 2: The design breakthrough!

The design experience gained in developing the patented Plössl, Wide-Field, and Nagler eyepieces resulted in an even more advanced concept: —8-element, 82° field designs (pat. pend.) with full correction of exit-pupil aberrations that permit the most comfortable viewing ever — night or day! Each model is a unique design, with a tailored eye relief like the 9mm Nagler, yet surprisingly compact, lightweight, and affordable. Extensive computer-aided design efforts and the use of new glass types retained the traditional superb full-field and fast-aperture sharpness. Of course, our pioneering lens edge-blackening, and multi-coating are included for maximum contrast.

A further important contribution to viewing comfort and effectiveness is a fold-down rubber eyeguard. This eliminates stray light and enhances dark adaptation to aid in detecting faint, delicate nebulosity and comets. The eyeguard is a delight on cold nights too.

20mm Nagler Type 2: This has the largest true field in the series, even larger than our 32mm Plössl. Yet this eyepiece, (strictly for 2 inch focusers) is comparable in size and weight to a 13mm Nagler. There's nothing like this 20mm for viewing large deep-sky open clusters, galaxies and nebulae. It gives a 4.5mm exit-pupil with f/4.5 telescopes. Daytime viewing is also simply stunning!

16mm Nagler Type 2: Offers far more true field than the 13mm Nagler, yet is similar to the 11mm in size! Great day or night performance with any telescope.

12mm Nagler Type 2: As superb as the 16mm, but with higher magnification. An excellent alternate to the 13mm or 11mm Nagler, which are preferable where the longer eye relief is of benefit to people who MUST wear eyeglasses to correct severe astigmatism.

The 16mm and 12mm TYPE 2 NAGLERS also work beautifully with Tele Vue Barlows. They both have 1¼" barrels that are parfocal with our other eyepieces and can also be used with 2" focusers.

Tele Vue

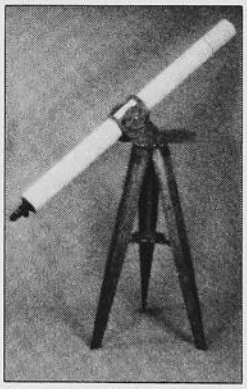
20 Dexter Plaza, Pearl River, NY 10965
(914) 735-4044

APPROXIMATE MAGNIFICATIONS WITH TYPICAL TELESCOPES

magnifications are with 1.8x Barlows magnifications are with 2.5x Barlows

Telescope Type		4"f/5.5 Renaissance	6"f/5	8"f/5	6"f/8 5"f/10 (C-5)	10"f/6 13"f/4.5	8"f/10 (C-8)	11"f/10 (C-11)
Telescope F.L. Inches		21.6	30	40	50	60	80	110
F.L. mm		550	762	1016	1270	1524	2032	2794
Barrel Diameter	Type 2 Nagler Eyepiece F.L.	Power						
2"	20mm	28x	38	51	64	76	102	140
		34	48	64	79	95	127	175
1¼"-2"	16mm	62 86	86 119	114 159	143 198	171 238	229 318	314 437
		46	64	85	106	127	169	233
1¼"-2"	12mm	83 115	114 159	152 212	190 265	229 317	305 423	419 582

THE BOTTOM LINE IS STABILITY



The Observer
Mount with
6" F/15 Tube Assy

MARTINS STAR TRACKER
INTRODUCES THE "OBSERVER" TELESCOPE MOUNT.

Based on a design by Richard Berry, this mounting is made to support long focal length high resolution refractors. A perfect companion for your Christen F/12, Brandt F/13.3 or even a Jaegers or Clavé 6" F/15. Rock solid, vibration free and silky smooth, it moves at a fingers touch. For those of you who enjoy just observing without the hassle of equitorial set-ups and power requirements, this mounting is made for you. Our deluxe version pictured above, is assembled from solid oak hardwoods, oak plywoods and oak veneers. All the joints are clamped and glued, all the hardware and fittings are solid brass. This is truly an archival mounting designed and built to last a lifetime and longer. We can also build a mount to your requirements or if you wish the entire instrument using Christen, Brandt, Jaegers or Clavé optics. We have less expensive and smaller versions as well as mountings made of ash, cherry, pine or maple. Allow 90 days for delivery. *Write for our brochure and full color photo of our deluxe version with a 6" F/15 tube assy.*

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GALAXY OPTICS

MANUFACTURERS OF QUALITY NEWTONIAN TELESCOPE OPTICS
QUALITY WORKMANSHIP - GUARANTEED • REFERENCES AVAILABLE

All ***GALAXY OPTICS ULTIMATE IMAGE™ MIRRORS*** are thoroughly tested throughout each stage of completion and are totally hand-figured and null tested to assure you of a professional quality diffraction limited paraboloidal optic.

GALAXY'S ULTIMATE IMAGE™ full thickness (1:6) and lightweight mirrors (2.00") are made from Precision annealed *molded* Pyrex mirror blanks and are available with a choice of three outstanding reflective coatings.

COATING #1: 88% Reflectivity - Aluminized and quartz overcoated
COATING #2: 96% Reflectivity - Broadband multilayer dielectric coating over aluminum
COATING #3: 98% Reflectivity - Broadband multilayer dielectric coating over silver

FULL THICKNESS 1:6 OPTICS

MIRROR	COATING #1	COATING #2	COATING #3
10"	$ 325	$ 375	$ 400
12.5"	475	550	600
14.5"	925	1125	1175
16.0"	1700	1950	2025
18.0"	2300	★	★
20.0"	3400	★	★

LIGHTWEIGHT 2.00" THICKNESS OPTICS

MIRROR	COATING #1	COATING #2	COATING #3
14.5"	$ 825	1025	$1075
16.0"	1100	1350	1425
18.0"	1300	★	★
20.0"	1650	★	★

GALAXY'S ultra-lightweight mirrors (1.6") are made from fine annealed Pyrex mirror blanks and are manufactured to the same specifications as our 1:6 mirrors.

ULTRA-LIGHTWEIGHT 1.6" OPTICS

MIRROR	COATING #1	COATING #2	COATING #3
14.5"	$ 650	$ 850	$ 900
16.0"	950	1200	1275
18.0"	1100	★	★
20.0"	1400	★	★

★ 18" and 20" enhanced aluminum and enhanced silver coatings by special request only.

ULTIMATE IMAGE™ ELLIPTICAL DIAGONAL FLATS
LASER QUALITY - TRUE 1/10 WAVE FLATS
1/10 WAVE, 20/10 SURFACE QUALITY - GUARANTEED

MINOR AXIS	COATING #1	COATING #2	COATING #3
2.1"	$ 75	$100	$115
2.6"	75	100	115
3.1"	95	120	150
3.5"	265	300	330
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All mirrors are available in many popular focal ratios. Full thickness (1:6) and ultra-lightweight Zerodur® Optics available. Mirror refiguring services, write for quotation. For a complete product catalog mail $1.00 to:

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LUMICON

HIGH PERFORMANCE TELESCOPE PARTS

ASTROPHOTO OF THE MONTH

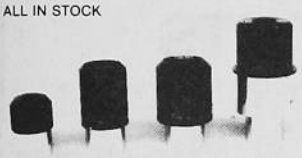
Spiral Galaxy M-99 (NGC 4254) in Coma Berenices. Spiral structure detail can be seen visually for this 10th magnitude galaxy. 40 minute photo by Dr. Jack Marling using hypered 2415 film, 24" f/6 telescope and LUMICON Giant EASY-GUIDER.

20mm NAGLER

New 2" eyepiece with 82° field $295

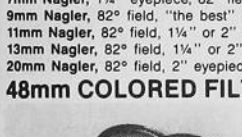
TELE VUE™ EYEPIECES USE THE BEST!!

ALL IN STOCK



Renaissance 4" f/5.5. Telescope	**$1395**
7.4, 10.4, 13, 17, 21, 26mm Plossl, 50°	**$95**
1.8X or 2.5X Tele Vue Barlow Lens	**$95**
32mm Plossl, widest true field in 1¼"	**$110**
55mm 2" Plossl, widest possible field	**$190**
15mm Wide-Field, 1¼" eyepiece, 65°	**$130**
19mm Wide-Field, 1¼" eyepiece, 85°	**$145**
24mm Wide-Field, "superb," 65°	**$160**
32mm Wide-Field, 2" eyepiece, 65°	**$230**
40mm Wide-Field, "awesome," 65°	**$295**
4.8mm Nagler, 82° field	**$150**
7mm Nagler, 1¼" eyepiece, 82° field	**$185**
9mm Nagler, 82° field, "the best"	**$225**
11mm Nagler, 82° field, 1¼" or 2"	**$240**
13mm Nagler, 82° field, 1¼" or 2"	**$250**
20mm Nagler, 82° field, 2" eyepiece	**$295**

48mm COLORED FILTERS



Upgrade to 48mm filters! All are multicoated

UV, Green, Yellow, Orange, Red	**$18 each**
48mm H-Alpha Pass (640nm cut-off)	**$35**
48mm Minus Violet (420nm cut-off)	**$29**
48mm High perform blue, 90% trans	**$35**
Central Star Filter (blue tri-color) 340-470nm bandpass	**$35**
UV-370 U-Band, 320-420nm bandpass	**$35**
48mm Polarizer (2 make variable density)	**$18**
Set 9 ea. 48mm filters ($259 list)	**$195**
2"/1¼" adapter threaded for 48mm filters	**$20**

H-ALPHA PASS FILTER

Yields spectacular contrast gains in B&W photography with telephoto lenses. Yields pinpoint star images. Superb with hypered 2415. For color, use the Minus Violet (MV) Filter.

Specify Lens Size	H-Alpha	(MV)
46, 48, 49mm	**$35.00**	**$29.00**
52, 55, 58, 62mm	**$45.00**	**$35.00**
67, 72, 77mm	**$52.00**	**$45.00**
82mm	**$55.00**	

Hypered 2415 film, 36 exp . . . **$10.95** . . . **3/$29**

LUMICON®

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Prices subject to change w/o notice.

NEW! ENHANCED SILVER DIAGONAL MIRRORS BOOST TELESCOPE PERFORMANCE

LUMICON 1.3" & 3.1" enhanced silver diagonal mirrors & 2" star diagonal.
The new LUMICON diagonal mirrors have a special enhanced silver coating with a protective overcoating for long life. Visible reflectivity is 98-99% compared to 86-89% for standard aluminum coated mirrors. The extra 10-12% transmission is like adding an inch of aperture! The substrate is fine annealed Pyrex flat to 1/8 wave.

1.32"	**$29.95**	1.52"	**$34.50**	1.83"	**$39.50**
2.14"	**$49.50**	2.60"	**$65.00**	3.10"	**$89.50**
4.25"	**$149.50**				

ENHANCED SILVER STAR DIAGONAL

90° star diagonals with above enhanced silver mirrors in a CNC machined black anodized aluminum body. Performance far exceeds prism diagonals.

1¼" (1.32" mirror)	**$89.50**
2" (1.83" mirror)(see photo above)	**$145.00**

OXYGEN-III FILTER

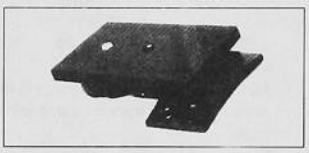
Helix Nebula, NGC 7293 in Aquarius. Bright and easy with Lumicon Oxygen-III Filter.

The ultimate in filter performance! The Lumicon Oxygen-III Filter has a contrast twice as high as the high performance Lumicon UHC Filter™. Use the Oxygen-III Filter for observing the very faintest planetary and diffuse emission nebulae. Also gives incredible views of bright nebulae (like M-27, M-17, etc.) from urban locations. Bandpass is 11nm, transmission is 90% for both O-III lines at 496nm and 501nm.

Filter Type	1¼"	48mm
Lumicon Oxygen-III	**$99.50**	**$199.50**
Lumicon UHC	**$99.50**	**$199.50**
Lumicon Deep-Sky	**$79.50**	**$119.50**
Set UHC and Oxygen-III	**$190.00**	**$380.00**

NOTE: The Oxygen-III Filter is not a substitute, but a compliment to the UHC Filter. **1 year guarantee:** You must see nebulae with the OIII filter that are **invisible** without a filter.

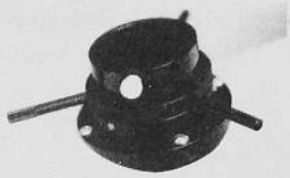
NEW ADJUSTABLE PIGGYBACK MOUNT



LUMICON has just designed a new adjustable piggyback mount ideal for all telescopes of 8-14" aperture. It has **both** vertical and sideways adjustment to allow optical alignment. It was designed to allow mounting of the LUMICON SUPER-FINDER on C-8, C-14, etc., but is ideal for any telephoto lenses or small telescopes.

Deluxe Piggyback Mount (State Telescope Type)	**$45.00**
LUMICON 12x80mm SUPER-FINDER	**$170**

LOW PROFILE NON-ROTATING HELICAL FOCUSER



LUMICON® DELUXE NON-ROTATING HELICAL FOCUSER on a 6" telescope.

LUMICON has just designed a deluxe smooth helical focuser with non-rotating 2" I.D. eyepiece holder. It has a vertical travel of 1¼" and a very low profile, only 1¼" high. It is CNC machined, black anodized, and a perfect match to a LUMICON Newtonian EASY-GUIDER.

Select your desired base-plate shape!
Flat, 7" OD, 9½" OD, 12½" OD, 16" OD, 20" OD, SUPER-FINDER base plate.

LUMICON Deluxe Helical Focuser	**$79.50**
3 handles (see photo)	**$12.95**
Helical focuser with 3 handles	**$92.45**
2"/1¼" adapter w/48mm filter threads	**$20.00**
2" LUMICON EASY-GUIDER	**$139.50**

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Protective plugs (left), vinyl dust covers.
Protect your valuable telescope optics, eyepieces and accessories with these black vinyl covers. Add $1 shipping. Deduct 10%, 2 or more sets.

1¼" O.D. plug, seals focuser	**4/$2**		
2" O.D. plug	**2/$2**	3½" O.D. plug	**$1.50**
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3½", 4½"	**$5**	16"*	**$20**
5½"	**$6**	19" (DS-16)	**$27**

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LUMICON HYPER-KITS™ yield 3-15X film speed gain in long exposures. They are safe & simple to use. Easy HYPER-KIT includes a chamber with all controls and fittings, thermometer, a refillable cylinder of non-flammable forming gas & hand-operated vacuum pump.

U.S. Patent 4,473,636

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MODEL 300 HYPER-KIT sensitizes any 35mm film in hours. Best for 2415. Achieves highest possible film speeds **$295.00**

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All **LUMICON EASY-GUIDER™** off-axis guiders† have both radial and 360° rotational adjustments for 5X ealser guide-star selection, use 48mm filters, 360° camera rotation, large prisms fo bright guide-starts. *Specify Camera and Telescope type.*
U.S. Patent # 4,448,500

NEWTONIAN EASY-GUIDER™

Full aperature. Installs in secs. Specify 2" or 1¼".

NEWTONIAN EASY-GUIDER	**$169.50**
3X Relay Diagonal (see photo)	**$79.50**
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CASSEGRAIN EASY-GUIDER™

For C-8, Meade 2080, Dynamax-8. Includes 50mm achromatic lens for f/5.8 operation-3X shorter exposures! **Superb rich field viewing, too!**

CASSEGRAIN EASY-GUIDER	**$225.00**
Adapter for Hasselblad **$185,** Mamaya 645	**$159**

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For Celestron-11, C-14, and the 10" Meade 2120. Includes 80mm clear aperture achromatic lens for edge-to-edge illumination & pin-point star images. F-ratio adjustable f/4-f/11. **Also yields unmatched Rich-Field viewing.**

GIANT EASY-GUIDER	**$395.00**
48mm DEEP-SKY Filter ordered with any EASY-GUIDER (SAVE $20)	**add $99.95**
Adapter for Hasselblad **$195,** Mamaya 645,	**$96**

WHAT DO YOU NEED?

1. **Illuminated reticle eyepiece** . . . **$79.50**
Lumicon 12mm eyepiece system has adjustible L.E.D. illumiation, dual crosslines, battery pack.
2. Cable release for long exposures . **$9.95**

3. **LUMICON Quartz Drive Corrector** **$219**
Dual-axis drive corrector is essential for astrophotography and/or field use of your telescope. 40Hz/80Hz variable output controls telescope drive. 60Hz Quartz reference ±12VDC Declination control output. Both 110VAC and 12VDC input for home or field use. Declination reverse switch for Newtonians.

Declination motor (state telescope)	**$70**
NEW Deluxe Digital Qtz. Drive Correc.	**$298**

HYPERSENSITIZED FILM

LUMICON Hypersensitized film is essential for good deep-sky astrophotography. Deduct 10% for 3 or more rolls (mixed o.k.).

Film Type, 35mm	Exposures	Price
2415, Ultra-fine B&W, red sens.	36	**$10.95**
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3M 1000, fastest slide film	20	**$12.95**
Fujichrome RD100, fine grain slide	24	**$12.95**
5072, color slides from neg	36	**$6.95**
D-19 B&W Developer	1 gal.	**$6.95**

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See TM#20, pages 30 through 34, for our "Index to Back Issues," listing issues #1 through #20, or write to the address below for an updated index.

☐ **Please send me the TM Back Issues I've circled below (note: TM #1 & 2 are printed and bound as one issue and count as one back issue).**

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